Periphyton growth in the Waipara River, North Canterbury

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Abstract

Periphyton was monitored monthly at four sites on the Waipara River from July 1999 to January 2002. Interactions with river flows, nutrients and invertebrates were examined to determine how these factors controlled periphyton development.

Comparison of the Waipara River to other New Zealand streams indicated that periphyton biomass at the uppermost site (Site 1) was generally low to moderate. Further downstream, moderate to high biomass occurred at sites 2 and 4. Biomass at Site 3 was generally low, although some very high values occurred on occasions. Periphyton biomass at sites 2 and 4 exceeded periphyton guidelines for the protection of aesthetic/recreational values at least once during each full year monitored. In contrast, the guidelines were rarely exceeded at Site 1.

Dissolved inorganic nutrients were generally poor indicators of the nutrient status of the river because of plant uptake. Cellular N and P values indicated nutrient enrichment at sites 2 and 4, which correspondingly had the highest biomass values. Conductivity tended to positively correlate with temporal and spatial patterns in periphyton biomass and was useful as a surrogate indicator of nutrient supply regimes. It correlated negatively with river flows, indicating higher nutrient concentrations may occur during reduced flows.

Notable differences occurred in biomass development between periods of contrasting flow regimes. In particular, annual mean and maximum biomass at the three downstream sites was considerably higher during a period of low stable flows compared to a period of higher base flows. However, at the uppermost site, differences in biomass between these periods were much less pronounced.

Invertebrate densities increased significantly with increasing periphyton biomass at the three downstream sites. There was little indication that invertebrates had any major control on periphyton biomass at these sites. However, at the uppermost site, although the invertebrate densities were generally much lower than at the other sites, they are more likely to have a controlling influence on periphyton biomass.

Overall, the nutrient supply regime of the Waipara River is the primary controller on biomass development. Flow regimes (both frequency of disturbance and extent of low flows) operate as secondary controls of biomass.

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To my friends, thanks for your support and understanding and for not inviting me to movies and on tramping trips during the final months. To Dave, thanks for taking me to the movies during the final months and for keeping me smiling. Finally thanks to Mum for your patience and I look forward to finally spending some time with you soon.

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1 Introduction

1.1 Periphyton in lotic environments

In unshaded rivers and streams, periphyton is a primary source of energy within the natural ecosystem. Algae are the main component of periphyton communities, which also include bacteria, fungi and protozoa. In stable flowing, nutrient enriched streams, periphyton can proliferate, causing water management problems. Adverse effects of high periphyton biomass include degradation of instream values such as aesthetic and recreational values, clogging of water intake structures, alteration of habitat for invertebrate and fish, and odour and taste problems for industrial and potable water supplies (MfE, 2000). Because of their rapid response to environmental change, periphyton communities are also useful as indicators of stream water quality and ecosystem health (Biggs, 1996; MfE, 2000).

1.1.1 Factors affecting periphyton development

The development of periphyton in rivers and streams is controlled by a complex series of interactions between hydrological, water quality and biotic factors (Biggs, 1996). Biomass accrual is controlled by the availability of resources, which are in order of importance; nutrients, light and temperature (Biggs, 1996). In unshaded streams, inorganic nutrients tend to be the controlling resource. Disturbance by flow perturbations result in loss of biomass through the mechanisms of substrate instability, shear stress from water velocities and abrasion from suspended solids (Horner *et al*., 1990; Biggs, 1996; Biggs *et al*., 1999a). Grazing of periphyton by invertebrates and fish also contributes to loss of biomass (Winterbourn, 1990; Rosemond, *et al.*, 1993; Steinman, 1996).

These interactions operate in a hierarchy of controlling factors (Biggs, 1995, 1996). Broad-scale studies of the relative importance of various factors influencing periphyton development in New Zealand gravel bed rivers have shown climate, topography and land use/geology to be overarching controllers of inter-catchment variations in periphyton biomass (Biggs & Close, 1989; Biggs, 1995). Land use and geology control nutrient supply regimes to rivers, which influence the rate and magnitude of biomass accrual. Climate and topography determine frequency of disturbance events (floods), water velocities (affecting shear stress) and substrate particle size and stability, which act as constraints on biomass development. These broad-

scale factors control the medium term (yearly) patterns in inter-catchment variations in biomass production.

Within a river catchment, localised variations in resources and physical forces will determine periphyton development along the length of the river. At the local habitat scale, the effects of shading, temperature, water velocity, nutrients, substrate type and grazing will further influence community development and can result in patchy distribution of periphyton communities (Biggs, 1996; Biggs *et al*., 1998a). In a study of two gravel bed rivers, Biggs & Gerbeaux (1993) found long-term (>1 year) average biomass correlated with macro-scale factors (geology/land use), while micro-scale habitat factors (e.g. velocities) were more important in short term (monthly) patterns in biomass development.

Water velocity can have contrasting effects on the biomass and composition of periphyton communities (Stevenson, 1996). Increasing velocities can positively influence biomass production by increasing nutrient availability through reduced thickness of the laminar boundary layer. However, increased velocities negatively impact on the biomass by increasing shear stress on algae. In a nutrient enriched stream, decreases in water velocity will have little impact on nutrient supply but will have significant impact on reducing shear stresses. As river flows recede during summer in nutrient enriched rivers, there is often a change in periphyton from low growing, diatom dominated communities to one dominated by filamentous green algae (e.g. Biggs & Price, 1987). The effects of reduced flow include reduced water velocities, increase in temperature, increase in nutrient concentration through less dilution, and an increase in light penetration into shallower water. It is proposed that at the local habitat scale, reduction in water velocity is a major contributor to the shift in community composition.

A study of the effects of low summer flows compared a site on the Waipara River with the nearby Okuku River (Suren *et al*., 2003a). Periphyton biomass in the Waipara River was considerably higher than that in the Okuku River, despite similar low flows. This was attributed to nutrient enriched water in the Waipara River compared to the unenriched Okuku River. Figures 1.1 and 1.2 show photos of prolific filamentous algae at two sites on the Waipara River, which were taken at approximately the same time as that study. These observations were made as part of Environment Canterbury's surface water quality monitoring programme (Hayward *et al*., 2003).

Figure 1.1 Filamentous algal growth at White Gorge, Waipara River, during a period of extreme low flows (February 1999).

Figure 1.2 Filamentous algal growth at Site 4, Waipara River, during a period of extreme low flows (February 1999).

1.1.2 Periphyton in New Zealand rivers and streams

Several studies have been undertaken to characterise periphyton growth on a broad-scale in New Zealand rivers and streams (e.g. Biggs & Price, 1987; Biggs, 1990; Biggs, 1995). In a survey of filamentous algae at 423 sites throughout New Zealand during a period of widespread drought, Biggs & Price (1987) found 167 sites with significant filamentous growths. In an extensive study of the ecological characteristics of rivers (Biggs *et al*., 1990; Biggs, 1990) periphyton and habitat conditions were surveyed in 101 sites during summer low flow conditions. High biomass (>20 g/m^2, AFDM) was found at 22% of sites. Eight periphyton communities were identified, of which filamentous algae taxa were dominant in six. Twenty-two habitat variables varied significantly across the community groups indicating strong habitat associations with periphyton communities. Conductivity was identified as the variable most strongly associated with community types, and it was suggested to be a useful indicator for classifying river habitats (Biggs, 1990).

Since 1989, the National Institute of Water and Atmospheric Research (NIWA) has undertaken a national water quality survey at 77 sites on major rivers in New Zealand (Smith *et al*., 1989). This programme (National Rivers Water Quality Network) has monitored water quality and periphyton cover on a monthly basis. In summarising the 13 years of data, Quinn and Meleason (2002) found the proportion of periphyton cover was highly variable. While filamentous algae and thick mats were often absent, nuisance levels of periphyton (>40% cover) occurred occasionally at nearly half the sites.

The Waipara River is one such river where prolific growths of filamentous algae have been observed during low flows in summer (CRC, 1992; Suren *et al*., 2003a). The Waipara River was included in the broad-scale study of filamentous algae in New Zealand rivers during a summer drought and dry winter in 1983 (Biggs & Price, 1987). In this study, moderate biomass (90% cover, 27 g/m^3 ash-free dry mass) of filamentous algae (dominant species, *Cladophora* sp.) occurred in summer, and a lower biomass (25% cover, 2 g/m^3 ash-free dry mass) dominated by *Ulothrix zonata* in winter.

1.1.3 Resource management and periphyton monitoring programmes

Under the Resource Management Act (1991), regional councils are charged with, among other duties, *"maintenance and enhancement of the quality of water in water bodies"*. This is achieved through the preparation and implementation of water resource plans, monitoring strategies, and consented activities.

Environment Canterbury is currently preparing its Natural Resources Regional Plan (NRRP). Consideration of the importance of protecting the natural state of waterways is a major focus of the water chapter of the plan (ECan, 1999a). This includes management of activities that directly or indirectly have potential to impact on periphyton development in streams. However, difficulties has arisen in identification the 'natural state' of Canterbury's waterways in terms of periphyton biomass. Up to the present, very little widespread and long-term monitoring of periphyton has been undertaken in Canterbury. This is partly because historical river water quality monitoring programmes focused on measuring organic and inorganic water column nutrients as an indicator of the potential for periphyton problems to develop (e.g. Meredith & Hayward, 2002). However, dissolved nutrient analyses alone can be poor predictors of periphyton biomass. This is because of the complex interaction of other controlling factors such as flow regime and habitat conditions. Despite these limitations of nutrient sampling, very little monitoring of the consequences of nutrient enrichment i.e. high periphyton biomass, has been undertaken to date. Mostly these have been limited to site specific investigations of periphyton growth (e.g. Norton, 1995; Norton & Valentine, 1995).

1.2 Aims of the project

The overall objective of this project was to investigate the mechanisms by which certain features of rivers, in particular nutrients and flow, affect periphyton growth. The Waipara River is used as a case study, where prolific algal growths are observed during low flows in summer (Biggs & Price, 1987; Suren, *et al.*, *2003a*). The project involved characterising algal growth in the river to determine the timing, magnitude and duration of high algal biomass, and investigating the mechanisms by which low flows affect algal growth.

Three main hypotheses were tested:

1. Prolonged periods of low flows during summer result in high algal biomass in the Waipara River.
2. Biomass will increase downstream as a function of nutrient enrichment.
3. Species composition of algal community will change with time from low growing, diatom dominated mats to communities dominated by filamentous green algae during prolonged periods of stable flow.

2 Study area

2.1 Physiography

The Waipara River flows along the northern fringe of the Canterbury Plains with a catchment area of 726 km^2, consisting of foothills, plains, downlands and some coastal ranges (Figure 2.1). It is approximately 40 km from its source in the eastern foothills of the Southern Alps to the sea at the northern end of Pegasus Bay (Chater, 2002). The catchment can be separated into two distinct parts. The steep rugged upper catchment is bounded by the Cavendish Hills to the northwest, the Okuku Ranges to the west, and Mt Karetu and Mt Grey to the south. The upper catchment is drained by four main tributaries; the North, South and Middle Branches of the Waipara River, and Tommys Stream. The lower catchment is dominated by the wide flat plains of the Waipara Alluvial Basin, and is bounded to the east by the Coastal Hills. Two main tributaries; Weka Creek and Omihi Stream flow from north of the lower catchment into the river on the alluvial basin (Lloyd, 2002).

2.2 Geology

The geology of the upper catchment consists of interbedded greywacke and argillite sediments (Greg, 1964). Some areas of marine tertiary sediments occur in the North Branch, Waipara River subcatchment. Below the confluence of the four main upper tributaries, the river flows through Ohuriawa Gorge into a trough cut into soft rock. It then enters White Gorge, which cuts through limestone escarpments (Mosley, 2003). Below the gorge, the river flows out onto the Waipara Alluvial Basin, which consists predominately of quaternary alluvial gravels. Weka Creek and Omihi Stream enter the river at the lower end of the basin. Both of these tributaries have significant amounts of marine tertiary sediments (limestone, sandstones and siltstones) in their headwaters. East of SH 1, the river enters the lower gorge in which further marine tertiary sediments are present.

NIWA has developed a GIS-based classification system for New Zealand rivers as a tool for ecosystem based resource management (Snelder *et al*., 2000). All rivers in Canterbury have been classified and mapped under this river environment classification (REC). The classification of rivers into management units is based on a hierarchy of physical characteristics of the catchment including climate, source of flow, geology, land cover, stream

order, and valley landform following a set of numerical rules. The classification of the dominant geology of the Waipara River is shown in Figure 2.1. Each river section is classified according to the dominating geological unit of the reach. The exception to this is where 'soft sediments' are present in 25% or more of the reach, in which case the section of river is classified as 'soft sedimentary'. This is because of the significant influence these sediments have on nutrient supplies to rivers, even when present in small amounts (e.g. Biggs & Close, 1989; Biggs, 1995).

The classification of the geology of the Waipara River consists of hard sedimentary geology along the main channel from the headwaters to Teviotdale Bridge. Weka Creek and Omihi Stream are predominantly soft sedimentary streams, as is the reach of the main river from Teviotdale Bridge to the sea (Figure 2.1). REC classifies the source of flow for the main stem of the river from its headwaters to the confluence with Omihi Stream as hill-fed. Below this point the river is classified as a lowland stream. This classification of the source of flow differs from that of Meredith & Hayward (2002), who proposed a simple intuitive classification of rivers based on source of flow and river morphology. In this system, hill-fed and mountain-fed rivers were further subdivided in to upper and lower sections arbitrarily separated by SH 1. The Waipara River was classified by Meredith and Hayward (2002) as a hill-fed river along its full length.

2.3 Land cover

Land cover in the upper sections of the Waipara catchment consists mainly of short tussock vegetation, scrub and rough introduced grassland. Low density grazing of sheep and cattle occurs (Lloyd, 2002). Exotic forestry represents a small but growing land use in the upper catchment.

Overall, prime pasture makes up about 55% of land cover, occurring mainly in the middle to lower catchment. The pasture is primarily used for moderately intensive dry land grazing of sheep, cattle and deer. An increasing proportion of the lower catchment is irrigated for viticulture, olive groves and other horticultural activities (Lloyd, 2002).

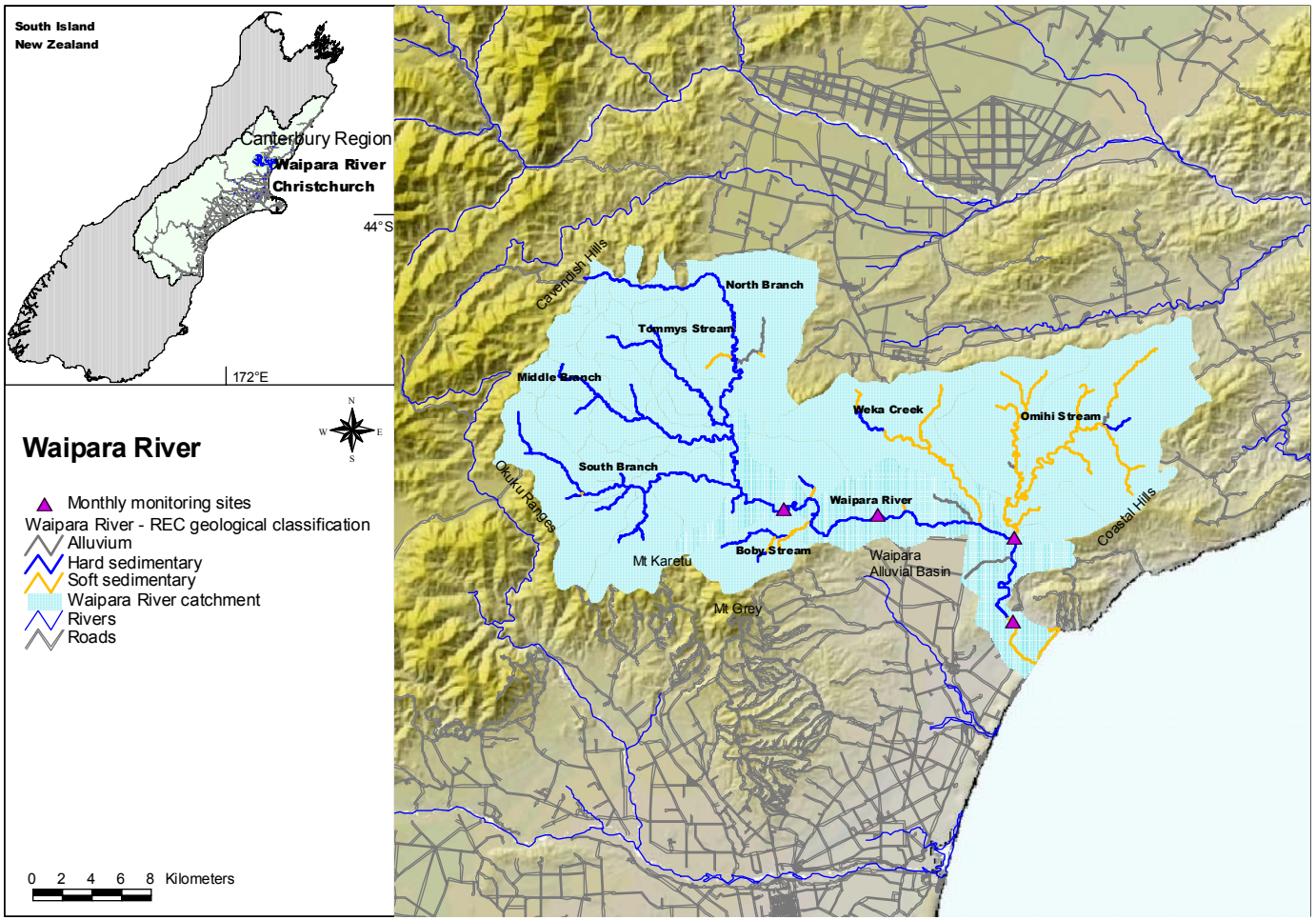

Figure 2.1 Waipara River catchment and geological classification of the Waipara River and main tributaries.

2.4 Instream values

The Waipara River supports a number of native fish species including upland, bluegill and common bullies, Canterbury galaxias, torrentfish, inanga, and longfin and shortfin eels (Richardson *et al.,* 2003). Limited numbers of trout have been observed, but the Waipara River is not renown as a trout fishery (Mosley, 2003). The riverbed provides a nationally significant habitat for indigenous birds including the endangered wrybill, black-fronted tern, banded dotteral and bittern. Recreational use of the river includes off-road vehicle operation, camping, picnicking, swimming and fossil-hunting (Mosley, 2003).

2.5 Resource use

Environment Canterbury currently authorises abstraction of a total of approximately 1300 l/s of water from the Waipara River and its tributaries (Chater, 2002). Of this, 1149 l/s are allocated for off-stream storage facilities taken during high flows (e.g. Glenmark Irrigation Scheme; Mosley, 2003). The total water allocated for direct use for summer irrigation is 120 l/s. The total authorised abstraction of hydraulically connected groundwater is 32 l/s. The actual volume of water abstracted is indeterminate but Environment Canterbury experience indicates that this is likely to be about 50% of allocation (Mosley, 2003). Concerns have been raised that the water resources of the Waipara River have been heavily allocated, which may have potential adverse effects on both instream values and consented water users (Lloyd, 2002). There are potential impacts of over-abstraction such as loss and degradation of instream habitat and degradation of water quality. Continued land development in the catchment may place further pressure on water resources. There are no consented discharges into the river that are likely to impact on the water quality.

2.6 Flow regime

The mean annual flow at White Gorge, based on 12 years of data from 1989 – 2001, is 303 l/s (Mosley, 2003). Generally the river gains flows between White Gorge and the river mouth, predominately from inflow of Omihi Stream and Weka Creek. Some groundwater inflow occurs along the alluvial plain, but most gains in flow are from tributary inflow. The flow

pattern is strongly seasonal where long periods of low flows can occur during the months of November to April (Chater, 2002).

A comparison of hydrological data for 83 New Zealand rivers presented by Clausen & Biggs (1997) with data for the Waipara River is shown in Table 2.1. The Waipara River has a relatively small average discharge. The coefficient of variation (CV) for the Waipara River was 2.8. Values above 2 are considered to indicate flow regimes with long periods of stable flows and a few high peaking floods (Clausen & Biggs, 1997). The Q_{90} calculated for the Waipara River was lower than the minimum reported by Clausen & Biggs (1997). This low flow variable indicates the extreme nature of low flows in the Waipara River. The average number of floods per year exceeding three times the median flow (FRE_3) was just below the average obtained by Clausen & Biggs (1997). Therefore, the hydrological regime of the Waipara River can be described as a small sized, foothill-fed river, with low to moderate frequency of high flood events, but which is subject to prolonged periods of low stable flows.

Table 2.1 A comparison of hydrological variables for the Waipara River based on 14 years of flow data (July 1988 to June 2002) collected by Environment Canterbury at the White Gorge flow recorder. Mean daily flows were used in these calculations.

Variable	Waipara River values	Average values (ranges) calculated for 83 NZ rivers (Clausen & Biggs, 1997)
Mean flow (m^3/s)	3.1	24 (0.41-520)
Median flow (m^3/s)	1.0	18 (0.26-468)
CV	2.8	1.1 (0.09-3.7)
Q_{90}	0.12	0.43 (0.17-0.98)
Floods above 3xmedian flow (3 m^3/s) (FRE_3)		
Average no. floods per year	6.1	10 (0-34)
Average no. of accrual days	44	
Average longest accrual period per year	115	
Floods above 10 m^3/s		
Average no. floods per year	4.3	
Average no. of accrual days per year	79	
Average longest accrual period per year	211	

3 Methods

3.1 Site selection and assessment

Four sites were selected on the Waipara River to obtain a spatial spread down the river from the mid-catchment to the lowland reaches of the river. Figure 3.1 shows the location of the four monthly monitoring sites. A suitable run (section of river with a smooth flowing surface) was selected at each site. Runs were selected that were as similar to each other as reasonably possible with regard to substrate type, degree of shading, riparian vegetation, water depth and velocity. A permanent reference point was marked at the upstream end of the run at each site (usually using coloured tape around a tree branch or marking a fixed bolder). From this reference point, a 10 m length of rope marked out the run within which assessments were made. The same reference point was used on each sampling occasion.

A large flood in August 2000 resulted in major changes to river channels at sites 2, 3 and 4. This meant new runs had to be found. As previously, runs were selected which were as similar as possible to the original sites. These runs were monitored for the remainder of the monitoring programme, except at Site 3. At this site, moderate sized floods often resulted in small changes to the river channel, so that the monitoring run was occasionally moved by up to 20 m from the original site.

All runs were largely unshaded for most of the day. Some introduced riparian vegetation (willow) was present along parts of the riverbanks at most sites but in general the sites were open gravel beds (Figures 3.2 to 3.9). Detailed description of the sites are given in Appendix 1.

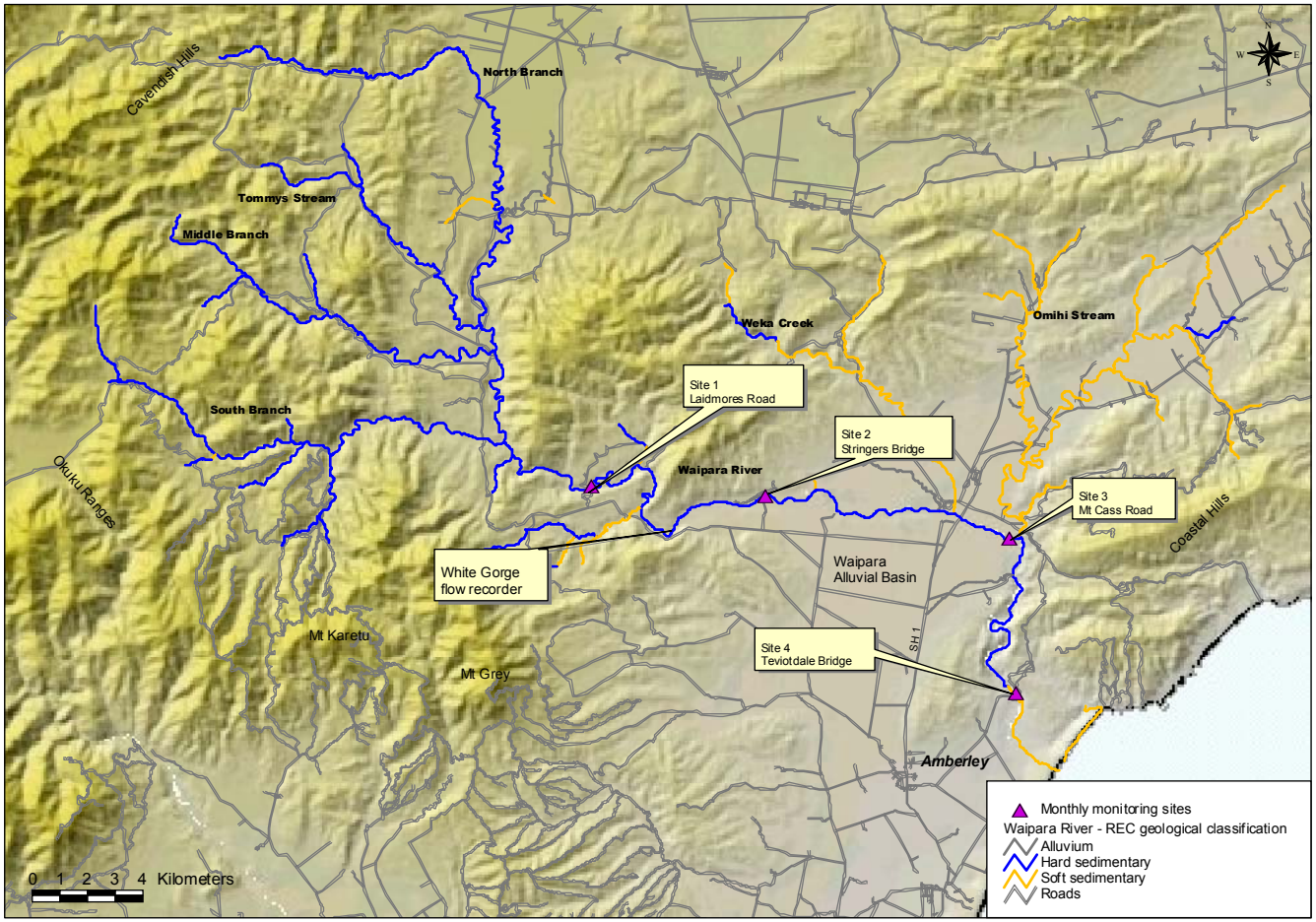

Figure 3.1 Monthly monitoring sites on the Waipara River.

Figure 3.2 Site 1 - Run 1, Laidmores Road (4/11/99)

Figure 3.3 Site 1 - Run 1, Laidmores Road (7/2/01)

Figure 3.4 Site 2 - Run 1, Stringers Bridge (4/11/99)

Figure 3.5 Site 2 - Run 2, Stringers Bridge (7/2/01)

Figure 3.6 Site 3 - Run 1, Mt Cass Road (4/11/99)

Figure 3.7 Site 3 - Run 2, Mt Cass Road (7/2/01)

Figure 3.8 Site 4 - Run 1, Teviotdale Bridge (4/11/99)

Figure 3.9 Site 4 - Run 2, Teviotdale Bridge (7/2/01)

3.1.1 Substrate size assessment

During the summer of 1999, and again in January 2001, an assessment of the substrate particle size was undertaken at each run. The 'Wolman' procedure was followed as described by Biggs *et al*. (1998b). This involved randomly collecting 100 stones by moving in a zig-zag manner up the 10 m length of the run and retrieving the first stone encountered, without visual selection, at every second step. The x, y and z dimensions of the stone were measured using a calliper. Appendix 2 summarises this data.

3.2 Monthly monitoring survey

3.2.1 Habitat assessments

On each sampling occasion, the surface velocity, water depth and wetted channel width were measured (Biggs *et al*., 1998b). An estimate of the surface velocity along the middle of the channel was made by timing a floating object along the 10 m length of reach. Three measurements were taken to obtain an average time.

Stream width measurements were made using a measuring tape to record the width at the upstream, midstream and downstream markers. Similarly, the depth was measured at each of the upstream, middle, and downstream points, at mid channel and at approximately 1 m from the river edge on each bank. Stream water temperatures were taken on each sampling occasion using a YSI dissolved oxygen meter.

3.2.2 Periphyton and invertebrate assessment and sample collection

Two transects were set up across the width of the stream at each site. At five evenly spaced points across each transect, a stone was selected by bending down to lightly touch the bed sediments without looking at what was there. This first stone encountered was picked up. However, if a boulder or a very small sized stone was picked, then the nearest one that could be picked up was retrieved (Biggs, *et al*., 1998b). The five stones were placed in a marked tray so that the sequence of stones collected could be identified and returned to the riverbank for assessment. The upper surface of each stone was examined and the percent cover of different periphyton forms was visually estimated and recorded (see Appendix 3 for example of field sheet). The stones were then examined over the full surface to count the number of

invertebrates present (the stones were examined carefully so that the periphyton was not significantly disturbed). The SHMAK invertebrate identification chart was used to identify the different invertebrate groups. From February 1999, the *x, y* and *z* dimensions of each stone was measured using callipers to enable calculation of invertebrate densities.

Periphyton samples were then collected by using a circular container (450 mm diameter) to mark a circle over the central upper surface of the stone (Biggs & Kilroy, 2000). Using a scalpel, all periphyton outside the marked circle was scraped away and discarded. All periphyton within the scribed circle was scraped into a cleaned pottle using a scalpel and cleaned toothbrush. River water was used to aid rinsing off the material into the sample container. Material from all 10 stones was pooled into one container.

3.2.3 Water quality sampling

Water quality samples for nutrient analyses were collected following the procedures detailed in the Surface Water Quality, Groundwater Quality, Biological and Habitat Assessment Field and Office Procedures Manual (ECan, 1999b). Samples were generally collected during the hours of 9 am to 2 pm. Samples were collected from the main river channel avoiding the river margin. Using specially prepared (acid-washed) bottles provided by the laboratory, the bottles were rinsed once with river water and then directly filled (i.e. no field filtering of samples). The samples were immediately placed in cooled chilli bins for transport to the laboratory.

3.3 Laboratory analyses

3.3.1 Periphyton sample preparation

At the laboratory, periphyton samples were blended on moderate speed for 1-2 minutes. The samples were then made up to a known volume in a measuring cylinder. The volume was usually 300 ml unless there was very little periphyton material, in which case a smaller volume was used. Surplus river water from the water quality analyses was used to rinse out the blender and sample containers and to make up the volume of sample.

Samples were then sub-sampled into four separate containers for different analyses (chlorophyll *a* (chl. *a*), ash-free dry mass (AFDM), cellular N and P, community composition). Because of the tendency of the periphyton material to quickly settle out, care was taken to

ensure the material was continually suspended during sub-sampling by the use of a magnet stirrer. The samples for AFDM and cellular N and P, and chl. *a* were then frozen. The samples for taxonomic analysis were preserved using buffered formaldehyde (4 %).

3.3.2 Sample analyses

The methods for analysis of water and periphyton samples are summarised in Table 3.1.

Table 3.1 Details of methods for laboratory analyses of water quality and periphyton samples.

Determinand	Laboratory	Method
Water nutrient analyses		
Conductivity (COND)	Environment Canterbury laboratory	Radiometer CDM 2e meter
Nitrate/nitrite nitrogen (NNN)	Environment Canterbury laboratory	APHA 4500 NO_3-F (20^{th} ED) Automated cadmium reduction method
Total ammonia-nitrogen (NH_3N)	Environment Canterbury laboratory	APHA 4500 NH_3-F (20^{th} ED) Phenolhypochlorite method
Dissolved inorganic nitrogen (DIN)	Environment Canterbury laboratory	Calculation (NNN +NH_3N)
Dissolved reactive phosphorus (DRP)	Environment Canterbury laboratory	APHA 4500-P F (20^{th} Ed) Automated ascorbic acid reduction method
Total nitrogen Total phosphorus	Environment Canterbury laboratory	APHA 4500-N Org D (20^{th} Ed) APHA 4500-P B (20th Ed) Persulphate digestion followed by analysis as NNN/DRP above
Periphyton analyses		
Chlorophyll a (chl. *a*)	Environment Canterbury laboratory	APHA 10200 H (20_{th} Ed) Acetone extraction
Ash-free dry mass (AFDM)	Cawthron Institute	APHA 10300 D (20^{th} Ed)
Cellular nitrogen	Environment Canterbury laboratory	Environment Canterbury in-house method Kjeldahl digeston followed by automated analysis as ammonia (see above)
Cellular phosphorus	Environment Canterbury laboratory	Environment Canterbury in-house method Kjeldahl digeston followed by automated analysis as phosphate (see above)

3.4 Taxonomic examination of periphyton

Prior to examination of the periphyton samples, fresh samples of various forms of periphyton collected from the Waipara River were examined to build up a list of algal species. Species were identified to the lowest taxonomic level possible using the following texts: Biggs and Kilroy, 2000; Prescott, 1962; Dillard, 1989-1993; Krammer & Lange-Bertalot, 1991-1997; Komarek & Anagnostidis 1988. A list of all taxa found in the periphyton samples is given in Appendix 4. The tentative identification of some diatoms given by Biggs and Kilroy (2000) were used for those species matching their descriptions.

3.4.1 Relative abundance

A semi-quantitative method to determine relative abundance of taxa based on their contribution to sample biovolume was undertaken following the general procedures of Biggs and Kilroy (2000). This involved subsampling a well mixed sample into a counting chamber similar to a Palmer-Maloney counting chamber (Novis, 2001). The chamber was examined under 100X and 400X magnification on an Olympus BH-2 microscope. The whole chamber was initially scanned to generate a list of taxa observed. If the covering of cells on the chamber were too dense, a subsample was diluted and used for the analysis. If the cells were too sparse, the whole sample was placed into a long tube, and allowed to settle for at least 1 day. The supernatant was decanted off, and the sample rechecked for density. The aim was to have a reasonably full cover of cells on the chamber, but not overlapping. The chamber was then examined more closely to check identifications and rank the taxa in decreasing order of their contribution to the volume of cells relative to the most common taxa. The dominant taxon (or taxa if species are co-dominant) contributes the most volume to the sample. The relative ranking of taxa to the dominant taxon is as follows:

8	Dominant
7	Abundant
6	Common-abundant
5	Common
4	Occasional-common
3	Occasional
2	Rare-occasional
1	Rare.

Because a small volume counting chamber was used compared to that recommended by the Biggs & Kilroy (2000) inverted microscope method, samples were analysed in triplicate. The three analyses were then averaged to obtain a single relative abundance ranking for each sample.

3.5 Data analyses

The data was generally analysed in Microsoft Excel 2000 for producing statistical summary tables and time series plots. Box plots, Spearman Rank and matrix scatterplots and scatterplots with distance weighted least squares fitting lines were generated in Statistica (V6) (Statsoft, 1999). Wilcoxon signed rank, ANOVA's and Kruskall Wallis tests were performed in Systat (V) (SPSS, 1999).

3.5.1 Water quality data

Where concentrations of determinands were below the analytical limits of detection, the results were reported as 'less than' the detection limit by the laboratory. These non-detect data was converted to a value equal to half the detection limit for the purposes of data analyses.

3.5.2 Periphyton biomass data

The percent cover of the different periphyton groups was calculated as an average of the 10 stones examined for each site on each sampling occasion. For some analyses, the periphyton groups were further grouped together for simplicity.

On some sampling occasions, there was no periphyton present and therefore, no samples were collected. In these cases, a non-detection value of 0.3 mg/m^2 for chl. *a* and 0.6 g/m^2 AFDM was assigned to the dataset. For chl. *a* results, the limit of detection was 0.6 mg/m^2, in which case a value equal to half the detection limit was assigned. There were no non-detect data for the AFDM analyses because at low biomass levels there was insufficient material for all analyses. This meant that some samples were only analysed for chlorophyll *a.* In order to have a more complete dataset, AFDM was estimated from chlorophyll *a* data using the formula provided by MfE (2000) (Equation 1). This involved five samples.

Equation 1 Regression equation between chlorophyll *a* and ash-free dry mass measurements derived from analyses of 170 samples collected from a wide range of periphyton communities in New Zealand (MfE, 2000)

Ln chl. *a* (mg/m^2) = 0.338 + 1.396 x Ln AFDM (g/m^2)
(r^2 = 0.790, N = 170)

The relationship between chl. *a* and ADFM monthly measurements for the Waipara River is shown in Figure 3.10. While some scatter occurs, there was a good general correlation between these measures of biomass. The regression equation obtained from the Ln values was similar to that given by MfE (2000).

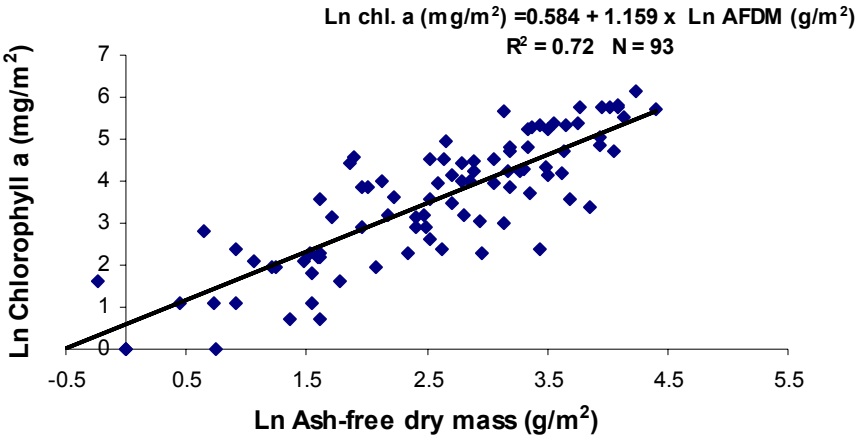

Figure 3.10 Relationship between monthly chlorophyll *a* and ash-free dry mass data for all sites on the Waipara River.

3.5.3 Invertebrate data

Analysis of the invertebrate data involved calculating the sum of each invertebrate group for the whole ten stones and then calculating the percent (relative abundance) of each group from total organisms counted. From January 2000, the dimensions of each stone was measured. This enabled calculation of invertebrate group densities. This was done by first calculating the surface area of each stone, using the formula provided by Biggs & Close (1989) (Equation 2). The surface areas were summed and used to calculated the density of the invertebrate group for each site.

Equation 2 Calibration equation for the area of a stone from stone dimension (Biggs & Close, 1989)

$$\text{Area } (cm^2) = 1.59 + 0.811\,(xy + yz + xz)$$

Where x = stone breadth, y = stone length and z = stone height (cm)

4 Periphyton biomass and community composition

4.1 Introduction

Spatial and temporal patterns in periphyton development can be extremely heterogeneous and are very difficult to predict (Biggs, 1996). Factors such as flows, substrate variability, nutrient regimes and shading affect the micro- to reach-scale spatial variability in periphyton development. Periphyton proliferations can occur where the stream habitat is suitably stable and adequate resources are available (nutrients and light). In addition, proliferations can alter the instream habitat for other aquatic organisms e.g. invertebrates and fish. While biomass measurements and visual assessments of periphyton cover provide valuable information on the degree of algal proliferation, the taxonomic composition of the community provides an additional indication of the state of the ecosystem (McCormick & Cairns, 1994).

Two common quantitative measurements of periphyton biomass are chlorophyll *a* (chl. *a*) and ash-free dry mass (AFDM). Chlorophyll *a* analysis provides an indication of the total amount of autotrophic organisms in the sample. Ash-free dry mass is a measure of the total amount of organic material in the sample and includes living autotrophic and heterotrophic organisms, plus dead material including micro-organisms, invertebrates and terrestrial debris (Biggs & Kilroy, 2000). More subjective indicators of biomass involve visual assessments of the cover of different forms of periphyton.

The autotrophic index (AI) can be used as an indicator of organic enrichment of a stream. It is calculated as the ratio of AFDM:chlorophyll *a* (both measures in the same units) (MfE, 2000). Discharge of dissolved organic wastes into streams can favour growth of heterotrophic periphyton taxa, which can sometimes dominate over the autotrophic species (algae and cyanobacteria). The resultant slime growths are unsightly and can smother the streambed making it unsuitable for some groups of invertebrates. Calculation of the AI can provide an early indication of a shift in a periphyton community from autotrophic dominated taxa to heterotrophic dominated taxa. In general, AI autotrophic dominated communities have an autotrophic index of 1 – 100, and values above 400 are considered to be indicative of polluted waters (MfE, 2000).

This chapter examines the results of monthly monitoring of periphyton biomass and community composition at four sites. The aims of this part of the study were to determine:

- average and peak biomass at each site
- timing of peak biomass
- dominant algae species at each site
- seasonal variations in community composition.

A comparison is made of the biomass data to relevant periphyton guidelines to determine the general state of the river in terms of instream values.

4.2 Results

4.2.1 Monthly biomass measurements and visual cover estimates

Table 4.1 summarises monthly chlorophyll *a* and ash-free dry mass results for each site. Figure 4.1 shows the range chlorophyll *a* and ash-free dry mass data. There was a variable spatial pattern in periphyton biomass along the length of the river. Mean and maximum chl. *a* and AFDM values were lowest at Site 1. Mean chl. *a* and AFDM values were significantly higher at Site 2 (Table 4.1). The highest AFDM value occurred at this site, while the highest chl. *a* value occurred at Site 3. The highest mean chl. *a* and AFDM values occurred at Site 4. Biomass measurements at Site 2 were often higher than those at Site 3, although no significant difference was found between these sites (post hoc Tukey test - $p > 0.05$). While the mean AFDM and chl. *a* values were moderately low at Site 3, occasional high values (400 mg/m^2 chl. *a* and 69 g/m^2 AFDM) showed that a high biomass can develop at this site on occasions.

Calculation of the autotrophic index (AI) at the four monitoring sites showed particularly high values at sites 1 and 3 (Table 4.1). Average and median AI values at sites 2 and 4 were below the heterotrophic/autotrophic indicator threshold value of 400.

Table 4.1 **Summary of monthly periphyton biomass data** (ANOVA was performed on natural log transformed data, means with the same superscript were not significantly different as determined by the post hoc Tukey test at $p < 0.05$)

	Site 1	Site 2	Site 3	Site 4	Anova Statistic	Anova *P*
Chlorophyll *a* (mg/m^2)						
Mean	**13** [1]	**90** [2,3]	**56** [1,2]	**96** [3]	9.257	0.000
Geometric mean	3	30	9	41		
St. dev.	17	105	104	93		
Median	4	52	9	85		
Maximum	54	325	455	331		
n	31	31	29	31		
Ash-free dry mass (g/m^2)						
Mean	**8** [1]	**20** [2]	**15** [1,2]	**22** [2]	5.91	0.001
Geometric mean	3	10	5	13		
St. dev.	12	20	19	17		
Median	4	16	6	18		
Maximum	47	81	69	59		
n	31	31	29	31		
Autotrophic index						
Mean	**1314**	**382**	**618**	**345**		
St. dev.	2093	300	504	263		
Minimum	139	70	149	75		
Median	548	266	470	235		
Maximum	9400	1143	1938	1286		
n	19	26	22	25		

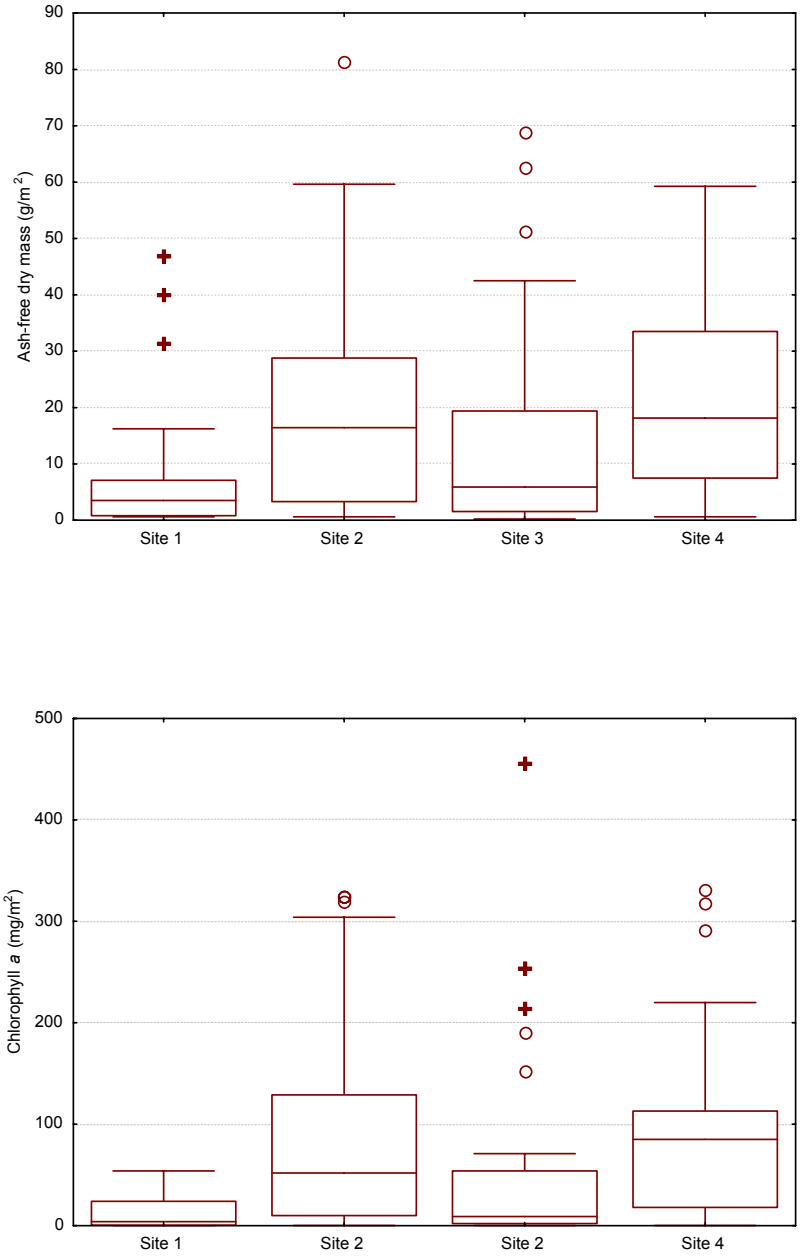

Figure 4.1 Range of chlorophyll *a* and ash-free dry mass values at each site[1]

[1] Note: horizontal bar = median, box =interquartile range, whisker ends = 5 and 95 percentile, o and + indicate outlier and extreme values respectively

Estimates of percent cover of periphyton on exposed substrata are summarised in Table 4.2. Mats of light brown periphyton growths were the most commonly observed forms of periphyton at all sites. Site 1 generally had the highest percent cover of thin mats, while prolific growths of thick mats occurred more commonly at sites 2 and 4 (Table 4.2). The occurrence of filamentous growths was rare at Site 1 compared to the other three sites. Site 2 had the highest maximum percent cover of filamentous algae.

Table 4.2 **Summary of visual estimates of percent cover of periphyton types of the exposed substrate surface** (Kruskall Wallis ANOVA, with the *P* value calculated assuming a Chi-squared distribution with 3 degrees of freedom)

Periphyton groups	Site 1		Site 2		Site 3		Site 4		Kruskal-Wallis test	
	mean	max.	mean	max.	mean	max.	mean	max.	Statistic	*P*
Thin mat/film (<0.5 mm thick)										
green	4	100	0	1	1	11	2	33	8.24	0.041
light brown	16	54	9	45	13	79	10	57	2.42	0.489
black/dark brown	1	27	0	1	0	2	0	5	1.61	0.658
Medium thick mat (0.5-3 mm thick)										
green	0	0	0	6	1	10	1	10	4.95	0.176
light brown	17	91	17	74	17	74	25	90	2.06	0.56
black/dark brown	1	18	2	20	1	20	4	57	6.64	0.084
Thick mat (>3 mm thick)										
green/light brown	5	67	13	83	5	68	12	96	4.58	0.206
black/dark brown	1	15	3	80	0	2	5	43	10.10	0.018
Filaments, short (<2 cm long)										
green	0	0	3	31	4	32	2	13	15.50	0.001
brown/reddish	0	6	13	88	3	47	9	87	13.24	0.004
Filaments, long (>2 cm long)										
green	0	2	3	43	5	59	2	24	2.32	0.508
brown/reddish	0	0	3	54	1	16	1	15	5.41	0.144

4.2.2 Comparison to guideline values

A number of provisional guideline values for periphyton are given in MfE (2000), which relate to the protection of different instream values (Table 4.3). These primarily focus on avoiding proliferation of periphyton. The main guidelines of relevance to the Waipara River are for the protection of benthic biodiversity and aesthetic/recreational values (Table 4.3).

Table 4.3 Provisional periphyton guidelines (MfE, 2000)

Instream value	Determinand	Diatoms/ cyanobacteria	Filamentous algae
Aesthetic/recreation (1 November – 30 April)	Maximum cover of visible stream bed	60% >0.3 cm thick	30% >2 cm long
	Max. AFDM		35 g/m^2
	Max. chlorophyll *a*		120 mg/m^2
Benthic biodiversity	Mean monthly chlorophyll *a*	15 mg/m^2	
	Max. chlorophyll *a*	50 mg/m^2	
Trout habitat and angling	Maximum cover of whole stream bed	N/A	30% >2 cm long
	Max. AFDM	35 g/m^2	35 g/m^2
	Max. chlorophyll *a*	200 mg/m^2	120 mg/m^2

Data for all sites exceeded one or more of the aesthetic/recreational guideline values on at least one occasion (Table 4.4). Maximum AFDM exceeded 35 g/m^2 at Site 1 during the summer of 2000/2001 (November to April) but not during the other two summers. The percent cover of mat or filamentous growths at this site did not exceed guideline values. At sites 2 and 4, several of the aesthetic/recreational guideline values were exceeded for percent cover and/or biomass during most summers. At Site 3, percent cover of filamentous algae and biomass values exceeded the guidelines during the 2000/2001 summer.

The maximum chl. *a* guideline value for the protection of benthic biodiversity was exceeded at Site 1 once each during 1999/2000 and 2000/2001. The mean chl. *a* value for 2000/2001 was just above the guideline value (Table 4.4). In contrast, maximum chl. *a* values for the other three sites exceeded the benthic biodiversity guideline value on several occasions each year. The annual mean chl. *a* values at these sites were consistently above the guideline value, with the mean chl. *a* values for 2000/2001 at sites 2 and 4 both being about 10 times greater than the guideline value.

Table 4.4 **Number of sampling occasions in which guidelines values for periphyton were exceeded.** Year periods were from July to June, except for 01/02 which was only for the period July 01 to January 02, Site 3 was not sampled during that period.

	Aesthetic/recreational guideline values (Nov-April)				Benthic biodiversity	
	Diatoms/cyanobacteria 60% >0.3 cm thick	Filamentous algae 30% >2 cm long	AFDM >35 g/m^2	Chl. *a* >120 mg/m^2	Mean chl. *a* >15 mg/m^2	Max. chl. *a* >50 mg/m^2
Site 1						
99/00	0	0	0	0	14.1	1
00/01	0	0	1	0	15.3	1
01/02	0	0	0	0	4.9	0
Site 2						
99/00	1	0	0	0	45.5	4
00/01	0	2	3	4	155.3	9
01/02	0	1	0	1	52.9	3
Site 3						
99/00	0	0	0	0	14.2	1
00/01	0	1	2	3	113.1	6
01/02						
Site 4						
99/00	1	0	0	1	65.5	7
00/01	2	0	3	3	147.8	8
01/02	0	0	0	0	59.9	4

4.2.3 Temporal patterns in biomass development

Figures 4.2 to 4.5 show the temporal variation in monthly biomass measurements at the four monitoring sites. The daily mean flows from a permanent water level recorder site at White Gorge are included in the graphs. Examination of the flow records for the two full years of sampling (1999/2000 and 2000/2001) showed very different flow regimes. In 1999/2000, frequent small floods and freshes occurred throughout the year, while a long period of stable low flows occurred from November 2000 to July 2001. These flow regimes had a large influence on the magnitude and timing of peak biomass measurements. This is discussed in more detail in Chapter 6.

The timing of annual peak biomass differed at each site and occurred at different times in each year. In addition, peak chl. *a* measurements sometimes occurred at different times to peak AFDM measurements. At Site 1, peaks in biomass occurred during spring and late autumn/early winter. The AFDM peak (39.9 g/m^2) in November 2000 was unusual in that was preceded by a major flood in August with prolonged high flows for several weeks following and that the chl. *a* value was relatively low (autotrophic index was 1109). The percent cover of periphyton at this site was correspondingly high with 78% cover of median thick to thick, light brown coloured mats. The peak AFDM in July was also associated with a relatively low chl. *a* value (autotrophic index of 1563).

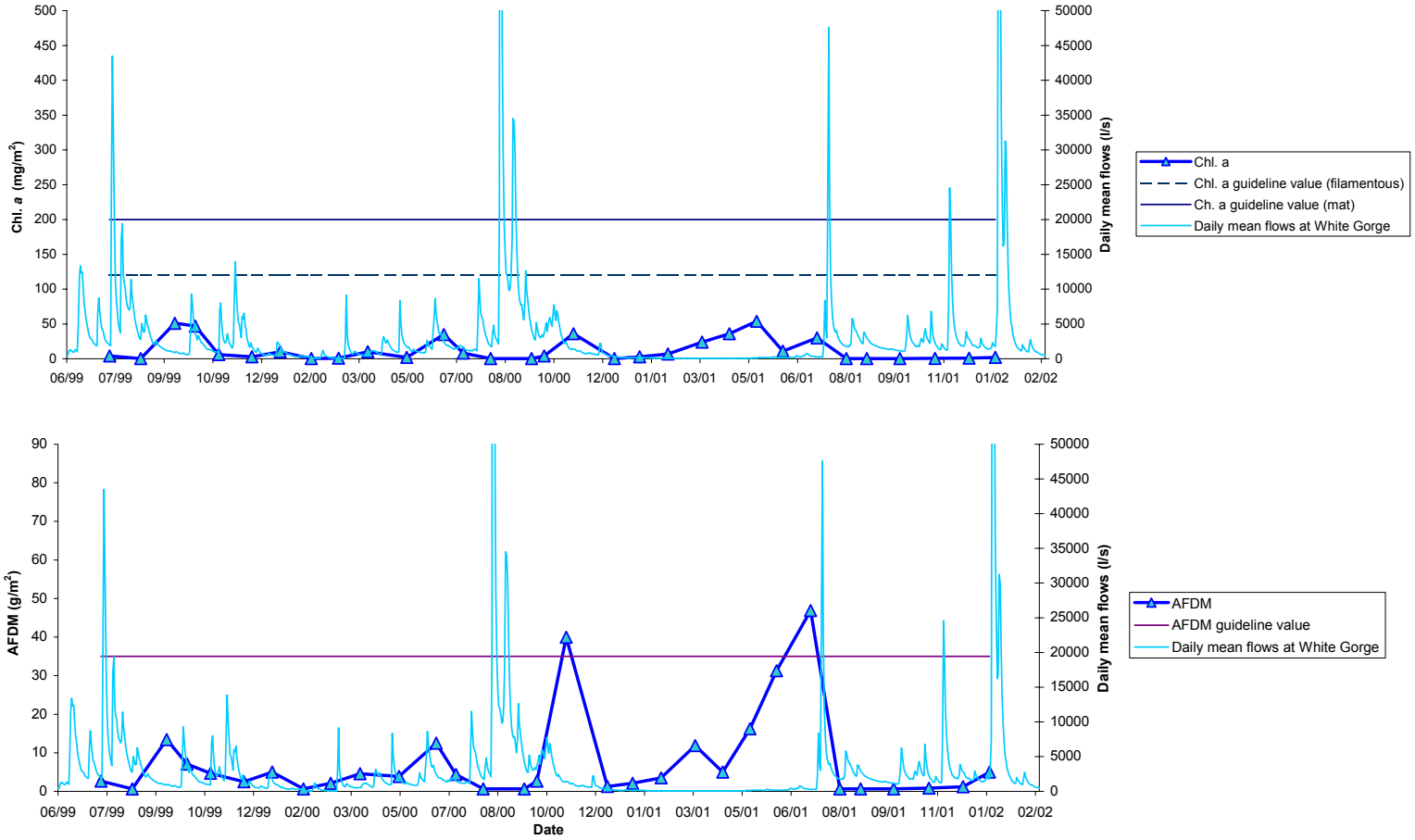

Figure 4.2 Monthly chlorophyll *a* and ash-free dry mass measurements at Site 1

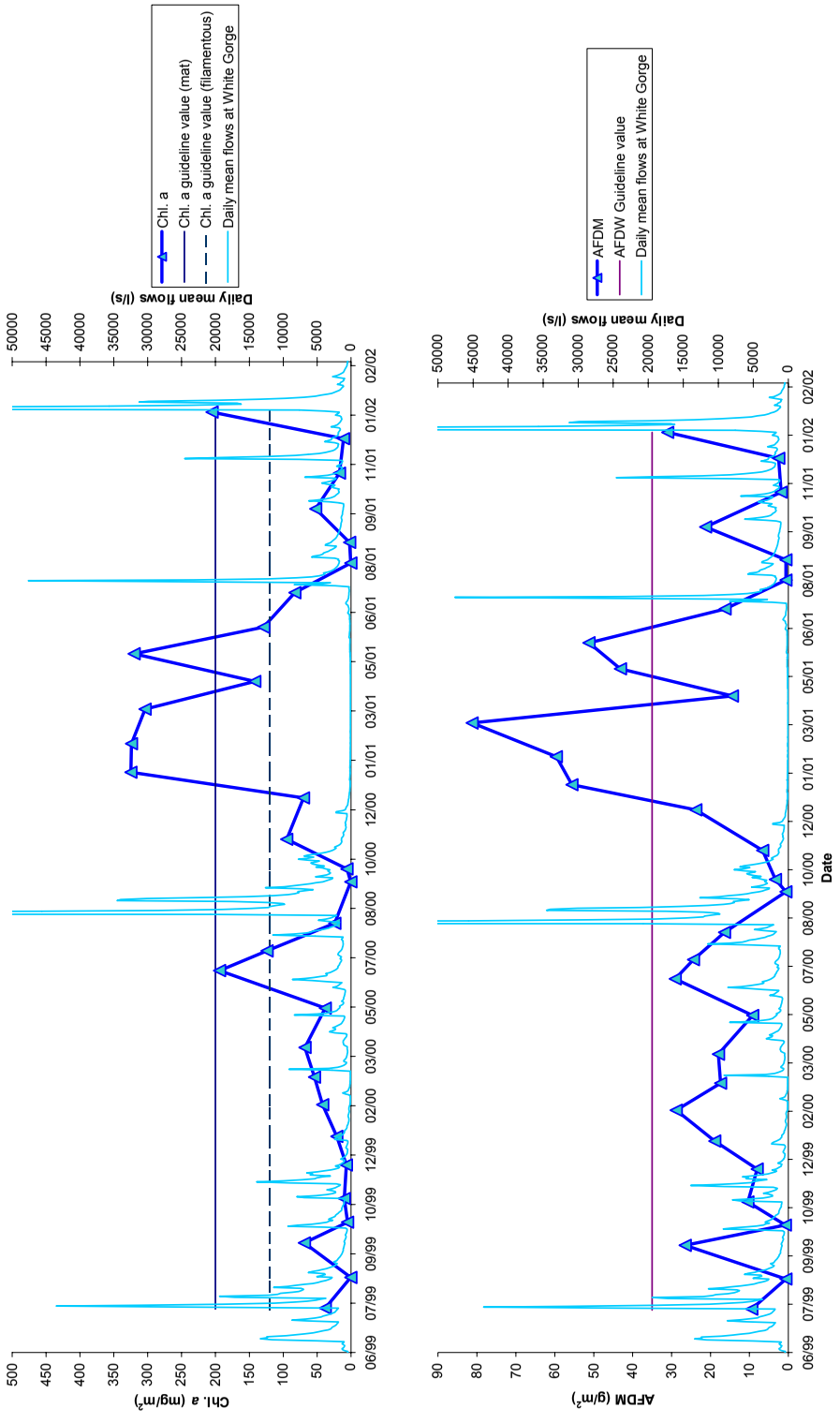

Figure 4.3 Monthly chlorophyll *a* and ash-free dry mass measurements at Site 2

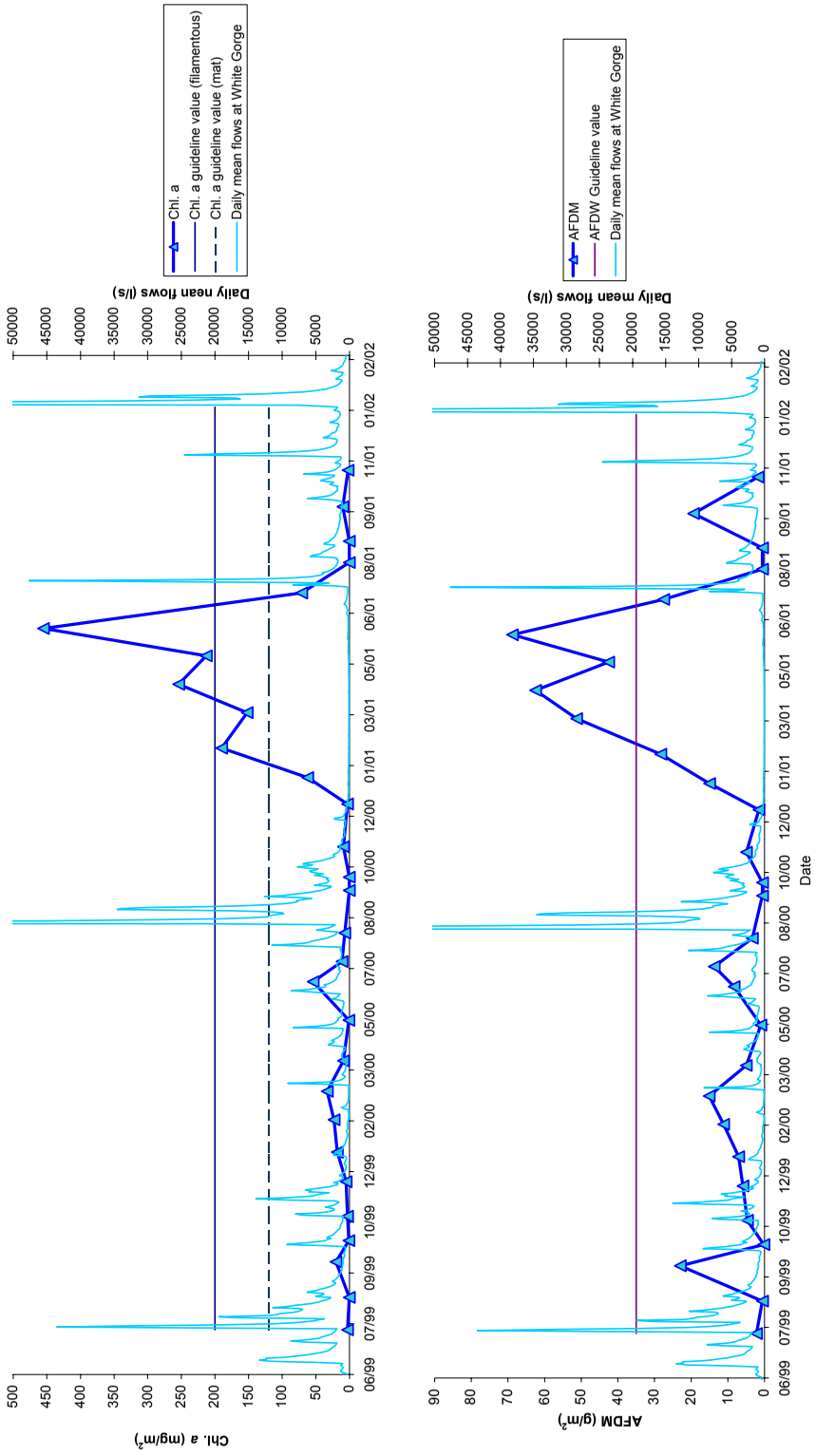

Figure 4.4 Monthly chlorophyll *a* and ash-free dry mass measurements at Site 3

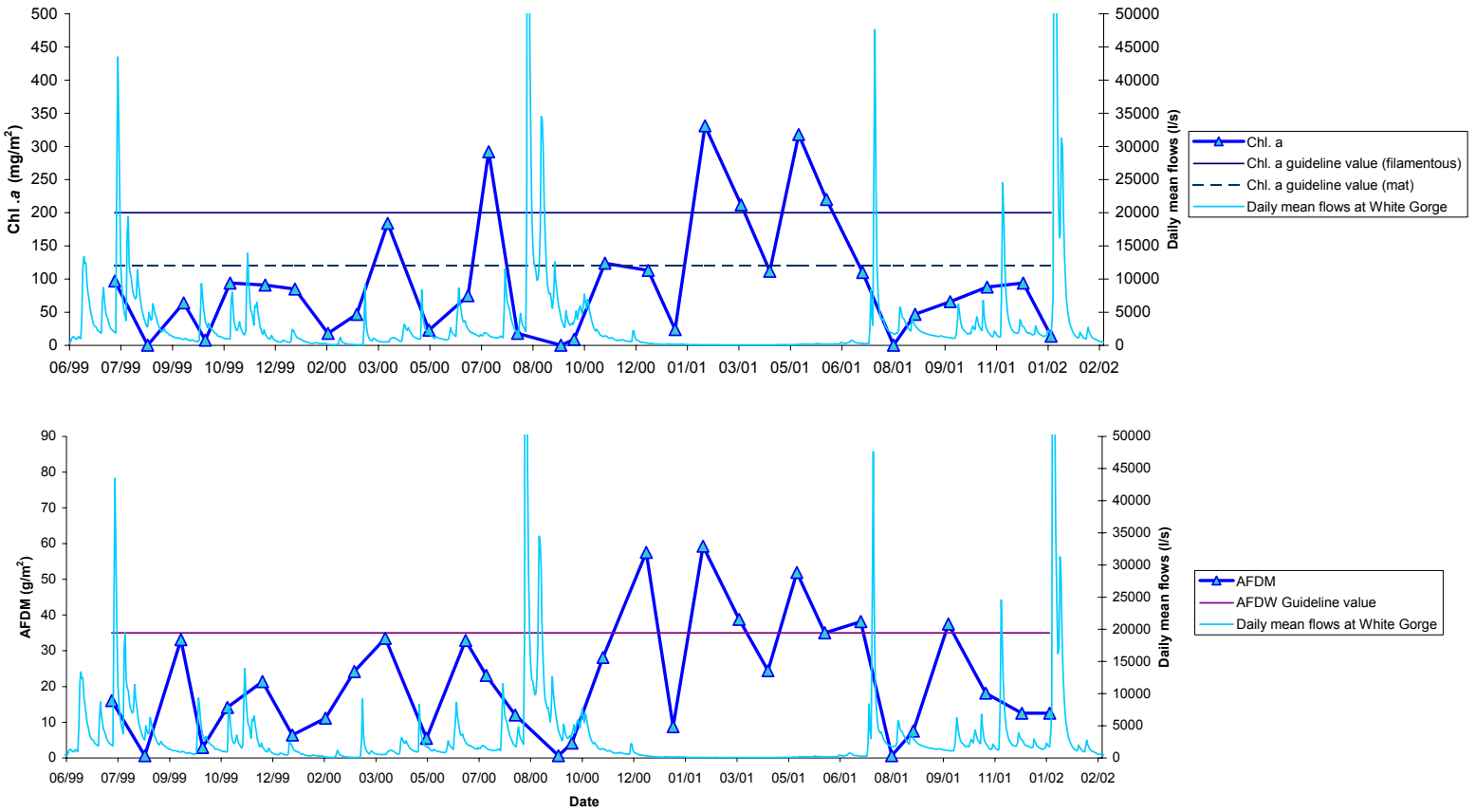

Figure 4.5 Monthly chlorophyll *a* and ash-free dry mass measurements at Site 4

At Site 2, small peaks in biomass occurred during spring, but in general peak biomass tended to occur during summer and autumn months. During the 2000/20001 year, when a period of particularly long stable flows occurred, a very high biomass occurred at Site 2, peaking in February/March. Samples collected in the following month showed a notable reduction in biomass. As there were no increases in flow, the loss of biomass presumably occurred as a result of autogenic sloughing and/or grazing. In the following months the periphyton biomass increased again, resulting in a second biomass peak during winter months (Figure 4.3).

Small peaks in biomass (especially for AFDM) occurred during spring at Site 3 but in general, peaks in biomass occurred during autumn. These were usually one to two months later than Site 2. At Site 4, the rate of biomass accrual appeared to be the most rapid, with peaks in biomass occurring earlier than at the sites 2 and 3. Several cycles of biomass accrual and loss occurred throughout the summer to winter period of 2000/2001.

4.2.4 Taxonomic composition of periphyton communities

The most commonly found taxa at each site are listed in Table 4.5. At sites 2 and 4, the four most abundant taxa were the same *(Gomphoneis minuta* var. *cassieae, Cocconeis pediculus, Cymbella kappii, Melosira varians)* and many of the other main species occurred in similar relative abundances. The four most abundant taxa at Site 3 were similar to sites 2 and 4, except for *Epithemia sorex* being the fourth most abundant taxa at this site instead of *Melosira varians.* Filamentous green taxa occurred in moderate abundance at these three sites, with *Cladophora glomerata* being the most commonly found filamentous green alga.

There were some notable differences in the common taxa found at Site 1 compared to the other three sites. In particular, *Cocconeis placentula* was the fourth most abundant taxa, while this species was much less common at the other three sites. Conversely, *Cocconeis pediculus* was common at the three downstream sites and much less common at Site 1. Filamentous green algae were overall much less abundant at this site with *Ulothrix zonata* being the most abundant.

Phormidium sp. was the most frequently found Cyanobacterium at all sites, but usually occurred in moderate to low abundance. *Lyngbya/Heteroleibleinia* sp. occurred in moderate abundance at Site 1, but occurred at much less abundance at the other three sites.

Table 4.5 Summary of average relative abundance (RA) scores in, order of decreasing abundance, of the main taxa for all samples analysed.

Site 1	D	TD	Ave. RA
Epithemia sorex	B	O-M	4.1
Cymbella kappii	B	O-M	3.9
Gomphoneis minuta var. *cassieae*	B	O-M	3.8
Cocconeis placentula	B	M	3.7
Melosira varians	B	M-E	3.5
Nitzschia c.f. *palea*	B	M-E	3.0
Navicula capitoradiatu	B		2.8
Gomphonema c.f. *minutum*	B		2.7
Cymbella tumida	B		2.3
Naviculoid sp.2	B		2.1
Synedra ulna var. 1	B	M	1.9
Navicula lanceolata	B	O-M	1.7
Synedra acus	B		1.7
Encyonema minutum	B	M	1.5
Cocconeis pediculus	B	M-E*	1.5
Nitzschia sp.4	B		1.4
Synedra ulna var. *contracta*	B		1.3
Fragilaria vaucheria	B	M	1.3
Ulothrix zonata	CL	O-M	1.3
Rhopalodia novae-zealandiae	B	O	1.2
Mougeotia sp.2	CL	M	1.2
Synedra ulna var. *biceps*	B	E*	1.2
Synedra ulna var. *ramesi*	B		1.2
Lyngbya/Heteroleibleinia sp.	CY	O-M	1.1
Phormidium sp.1	CY	M	1.0
Stigeoclonium lubricum	CL	M	0.9

Site 2	D	TD	Ave. RA
Gomphoneis minuta var. *cassieae*	B	O-M	4.6
Cocconeis pediculus	B	M-E*	4.5
Cymbella kappii	B	O-M	4.0
Melosira varians	B	M-E	3.6
Cladophora glomerata	CL	E	3.5
Synedra ulna var. *biceps*	B	E*	3.1
Naviculoid sp.2	B		3.0
Epithemia sorex	B	O-M	2.6
Gomphonema c.f. *minutum*	B		2.5
Navicula capitoradiatu	B		2.5
Cocconeis placentula	B	M	2.5
Nitzschia c.f. *palea*	B	M-E	2.3
Synedra acus	B		2.3
Navicula lanceolata	B	O-M	2.1
Synedra ulna var. *ramesi*	B		2.1
Encyonema minutum	B	M	2.0
Cymbella tumida	B		1.9
Synedra ulna var. *contracta*	B		1.9
Synedra ulna var. 1	B	M	1.9
Nitzschia sp.4	B		1.6
Ulothrix zonata	CL	O-M	1.5
Fragilaria capucina	B	O-M	1.4
Stigeoclonium lubricum	CL	M	1.4
Phormidium sp.1	CY	M	1.4
Fragilaria vaucheria	B	M	1.4
Rossithidium linearis	B		1.3

Site 3	D	TD	Ave. RA
Cymbella kappii	B	O-M	4.0
Cocconeis pediculus	B	M-E*	3.8
Epithemia sorex	B	O-M	3.3
Gomphoneis minuta var. *cassieae*	B	O-M	3.3
Gomphonema c.f. *minutum*	B		3.0
Synedra ulna var. *biceps*	B	E*	2.8
Naviculoid sp.2	B		2.5
Nitzschia c.f. *palea*	B	M-E	2.4
Navicula capitoradiatu	B		2.4
Cocconeis placentula	B	M	2.2
Melosira varians	B	M-E	1.9
Cladophora glomerata	CL	E	1.8
Synedra acus	B		1.7
Navicula lanceolata	B	O-M	1.6
Synedra ulna var. *ramesi*	B		1.6
Encyonema minutum	B	M	1.5
Synedra ulna var. 1	B	M	1.5
Cymbella tumida	B		1.5
Fragilaria capucina	B	O-M	1.4
Synedra ulna var. *contracta*	B		1.3
Nitzschia sp.4	B		1.3
Naviculoid sp.4	B		1.2
Rossithidium linearis	B		1.2
Achnanthidium minutissimum	B	O	1.1
Oedogonium sp.1	CL		1.1
Oedogonium sp.2	CL		1.1

Site 4	D	TD	Ave. RA
Gomphoneis minuta var. *cassieae*	B	O-M	4.8
Cocconeis pediculus	B	M-E*	4.4
Cymbella kappii	B	O-M	4.0
Melosira varians	B	M-E	3.9
Nitzschia c.f. *palea*	B	M-E	3.5
Synedra ulna var. *biceps*	B	E*	3.3
Cladophora glomerata	CL	E	3.3
Naviculoid sp.2	B		3.2
Encyonema minutum	B	M	2.8
Navicula lanceolata	B	O-M	2.5
Synedra ulna var. *ramesi*	B		2.5
Synedra ulna var. 1	B	M	2.4
Navicula capitoradiatu	B		2.2
Gomphonema c.f. *minutum*	B		2.2
Cocconeis placentula	B	M	2.1
Epithemia sorex	B	O-M	2.1
Stigeoclonium lubricum	CL	M	1.9
Synedra ulna var. *contracta*	B		1.8
Fragilaria capucina	B	O-M	1.7
Ulothrix zonata	CL	O-M	1.7
Synedra acus	B		1.6
Fragilaria vaucheria	B	M	1.5
Phormidium sp.1	CY	M	1.5
Rossithidium linearis	B		1.5
Achnanthidium minutissimum	B	O	1.3
Nitzschia sp.4	B		1.2

D – Division: B=Bacillariophyta, Cl= Chlorophyta, Cy=Cyanobacteria

TD – trophic designation: O=oligotrophic, M=mesotrophic, E=eutrophic (MfE, 2000)

* - common habitat inferred from Biggs and Kilroy's (2000) identification guide.

4.3 Discussion

In comparison to other rivers in New Zealand the Waipara River yields a moderate to high periphyton biomass in its lower reaches (below the upper gorge). In a study of 30 New Zealand hill-fed rivers, geometric means of chl. *a* values ranged from <1 to 281 mg/m^2, with 5 of the 30 sites having geometric means greater than 30 mg/m^2 chl. *a* (Biggs, 2000). Maximum chl. *a* values ranged from 9.1 to 1396 mg/m^2, with 7 of the sites having maximum chl. *a* values greater than 300 mg/m^2. This compares with sites 2 and 4 on the Waipara River with geometric means of 30 and 41 mg/m^2 and maximum values of 325 and 331 mg/m^2 respectively (Table 4.1). In separate study involving monthly monitoring of periphyton at 20 sites from 16 New Zealand rivers, 75% of the values were <80 mg/m^2 for chl. *a* and <10.8 g/m^2 AFDM, with median values of 20 mg/m^2 for chl. *a* and 5 g/m^2 for ash-free dry mass (Biggs, 1996). Median chl. *a* values at sites 1 and 3 were well below these median values. However, median chl. *a* and AFDM values for sites 2 and 4 were considerably higher. These comparisons indicate that periphyton biomass at Site 1 is generally in the low to moderate range, and is in the moderate to high range for sites 2 and 4. Biomass at Site 3 is generally in the low to moderate range, although some very high values occur on occasions.

The prolific nature of periphyton development at sites 2 and 4 is further indicated by biomass frequently exceeding guidelines for the protection of aesthetic/recreational instream values. This was particularly notable for the 2000/2001 year during which a period of prolonged stable flow occurred. The guidelines were only occasionally exceeded at Site 1 further indicating that biomass at this site was generally low. While the periphyton biomass at Site 3 was also generally low, some samples exceeded the guidelines during 2000/2001, and the highest chl. *a* value was recorded at this site.

These results indicate that the instream aesthetic quality and potential recreational values of the Waipara River, at least at sites 2 and 4, are moderately degraded by the amount and duration of prolific periphyton growths. The generally lower periphyton biomass occurring at Site 1 suggests that this site is likely to have a higher aesthetic and recreational value than sites further downstream. Guidelines for the protection of benthic biodiversity were frequently exceeded at the lower three sites suggesting that the aquatic ecosystem in lower parts of the

river may be in a less healthy[2] state than the upper reaches. Indeed, this has been indicated by benthic invertebrate and stream habitat monitoring undertaken by Environment Canterbury at four sites on the Waipara River (sites 1, 2, 4 and at Camp David (near SH 1)). This monitoring has shown in general a 'good' overall invertebrate grading for Site 1, and 'fair' to 'poor' overall invertebrate grading for the three downstream sites (Hayward *et al.,* 2003). The high periphyton biomass commonly found in the lower reaches is likely to be a contributing factor in these poor stream health gradings.

The various forms of algae can be used as indicators of stream health, where typically thin films of green or brown mats indicate healthy streams, while prolific thick mats of diatom/cyanobacterial communities and filamentous algae indicate poor health of the stream (Biggs *et al*, 1998b). The higher proportion of thin films found at Site 1 compared to the three downstream sites further demonstrate the healthier state of this site.

The relationship between chl. *a* and AFDM measurements can vary depending on the taxonomic composition of the periphyton community, light availability, non-photosynthetic organic debris, and the maturity of the community (MfE, 2000). In particular, some of the cases where the AFDM is relatively greater than the chl. *a* values appears to be linked to the taxa present in the samples, where some mucilage forming diatom taxa such as *Cymbella* and *Gomphoneis* species dominated the community composition, resulting in larger than usual organic matter compared to the chl. *a* pigments. This is the likely reason for some of the high AI values found at sites 1 and 3. In particular, the high AI values found at Site 1 during November 2000 and July 2001 were associated with high AFDM, exceeding guideline values. Common taxa in these samples included *Gomphoneis minuta* var. *cassieae* and *Cymbella kappii*. Biggs and Hickey (1994) recorded similar high AI values in samples from thick mucilaginous diatom communities dominated by *Gomphoneis, Cymbella* and *Gomphonema* species.

High AI values found on some occasions, especially at sites 1 and 3, are also likely to be the result of low biomass measurements (MfE, 2000). This index should really only be determined for samples with a reasonable biomass (e.g. > 2 g/m^2 AFDM). As there are no direct discharges of organic wastes into the Waipara River, it is unlikely the development of heterotrophic dominated communities occur as the result of pollution of the river.

[2] The term 'healthy' in relation to aquatic stream ecosystems refers to the overall 'condition' of the stream including water quality, habitat quality and the state of the biotic community.

The spatial pattern in periphyton biomass did not follow an expected pattern of generally increasing biomass with distance downstream (Biggs, 1996; Vannote *et al*., 1980). Low biomass generally occurred at the uppermost site, while some of the highest biomass values occurred at the next downstream site. Site 3 yielded generally lower biomass values than Site 2. Site 4 generally had a similarly high biomass to the second downstream site. This spatial pattern in biomass may reflect local hydraulic and habitat conditions rather than broad-scale catchment conditions. This is discussed in more detail in the following sections.

Seasonal effects on periphyton development can be a function of seasonality in disturbance regimes (providing adequate nutrient resources), seasonality in grazer activity (where flood disturbance is rare) or seasonality in light and temperature regimes (Biggs, 1996). Significant seasonal variations in biomass accrual on nutrient diffusion substrates were found in a study of 12 New Zealand headwater streams in which biomass accrual rates were greatest during summer and lowest in winter with intermediate rates during spring and autumn (Francoeur *et al.,* 1999). Similarly, seasonal variations in biomass on natural substrates were found in a study of six New Zealand temperate streams (Biggs & Close, 1989). In the Waipara River, some seasonal patterns in biomass were observed. In particular, small peaks in biomass commonly occurred during spring. These generally followed winter floods and may be the result of re-colonisation and accrual of periphyton proceeding faster than the re-establishment of grazing invertebrates, at least in the first 1-2 months following a disturbance. However, in general, the short-term pattern of biomass development in the river appears to be more influenced by the flow regime than seasonality.

The timing of peak biomass development during periods of stable flows in summer to early winter months differed among the sites. The relatively long period taken for peak biomass to be reached at Site 1 probably reflects the lower nutrient status of this site (Section 5) resulting in a slower rate of growth. In contrast the apparent rapid accrual rate at Site 4 appears to result in several cycles of large biomass accrual and subsequent sloughing during summer and autumn months. Similarly, peaks in biomass at Site 2 occur during early summer followed by cycles of sloughing/grazing loss and accrual during prolonged periods of stable flows.

Diatoms were the most common taxa found at all sites. In particular, *Gomphoneis minuta* var. *cassieae, Cocconeis pediculus, Cymbella kappii,* and *Melosira varians* were commonly found at the lower three sites. *Cladophora glomerata* was the most commonly found filamentous green alga at these sites. *Epithemia sorex, C. kappii, G. minuta* var. *cassieae* and *Cocconeis placentula* were the most abundant taxa found at Site 1.

In a conceptual model for stream periphyton, where disturbance and nutrient supply were the major axis on a habitat template, Biggs *et al.* (1998c) proposed grouping 35 common periphyton taxa into four main functional groups based on the C-S-R life histories of Grime (1977, 1979, cited in Biggs *et al.*, 1998c). Of the main taxa found in the Waipara River, *M. varians* and *C. glomerata* were assigned to C-selected taxa (competitive strategy) which occupied stable, nutrient enriched habitats. *C. kappii* and *G. minuta* var. *cassieae* were placed in R_2- selected taxa (ruderal) which are found in moderately stable and moderately enriched habitats. *E. sorex* was assigned to S-selected taxa (stress), which occupy stable, low nutrient habitats. *C. placentula* was assigned to the R4-selection taxa which occupy highly disturbed and low to highly enriched habitats. However, it was recognised that *C. placentula* is commonly found as an epiphyte on macroalgae, and as such could occur in stable habitats.

These functional groupings of the main taxa found in the Waipara River provide an indication of the stream habitat at each of the sites. In particular, dominant algal species found in the lower three sites are indicative of low to moderate disturbance frequencies and moderate to high levels of enrichment. Common taxa at the uppermost site are also indicative of low to moderate disturbance frequencies, but are found in habitats with low to moderate levels of enrichment.

5 Nutrients

5.1 Introduction

Elevated concentrations of plant nutrients (nitrogen and phosphorus) can result in proliferation of periphyton communities. In unshaded temperate streams, nutrient supply is a major controlling factor in periphyton growth (MfE, 2000). Nutrients operate within the habitat template with climate/flow regime being the primary controlling variable (Biggs, 1995; Biggs *et al.*, 1998c).

Natural sources of inorganic nutrients in streams include dissolution of different rock material, and breakdown of organic material in the soil and streambed. In un-forested river systems, there are limited natural organic sources of nutrients compared to forested streams, which have large inputs of organic detrital matter. Different rock materials have varying ability to release nutrients. Volcanic rocks and marine tertiary sediments are a particularly significant source of inorganic nutrients (especially phosphorus) even if only present in small amounts in a catchment (MfE, 2000).

Human activities can contribute significantly to nutrient supplies in streams. Point source discharges such as human and animal sewage effluent, animal processing wastes, and various manufacturing wastes can contribute greatly to stream nutrients. However, these types of discharges are becoming less common. Non-point discharges of nutrients arise from run-off, groundwater inflow and numerous small, frequent releases to streams. The intensity and management practices of land-use activities adjacent to streams and tributaries has a significant influence on nutrient run-off. In particular, run-off from fertiliser use and grazing animals can provide excess nutrients if allowed to enter waterways. Enrichment of groundwater recharged from areas of intensive land-use also provides additional sources of nutrients, especially nitrogen. Nutrient enrichment resulting from human activities generally increases in the lower reaches of rivers. This is because there is generally less land developed in the steeper upper catchment areas, while land use intensity is generally greater on the flatter land in lower catchment areas.

Phosphorus occurs in natural waters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates and organically bound phosphates. They occur in solution, in mineral and organic detritus and in living aquatic organisms. Phosphorus is

essential to the growth of organisms and can be the nutrient that limits aquatic primary production. Phosphates occur also in bottom sediments and in biological sludges, both as precipitated inorganic forms and incorporated into organic compounds (APHA, 1998). Dissolved reactive phosphorus (DRP) is a form of dissolved phosphate (orthophosphate) that is available immediately for plant and algal growth. Total phosphorus is a measure of the concentration of orthophosphates, condensed phosphates and organically bound phosphates in the water. This includes both dissolved and suspended particulate phosphates.

The forms of nitrogen of greatest interest in waters are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen. All these forms of nitrogen, as well as nitrogen gas (N_2), are biologically interconvertible and are components of the nitrogen cycle (APHA, 1998). The nitrate ion (NO_3^-) is the common form of fully oxidised nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion can be further reduced to ammonia (Chapman, 1992). Nitrate and nitrite-nitrogen (NNN) is also called total oxidised nitrogen.

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. It is also discharged into water bodies by some industrial processes and as a component of community waste (Chapman, 1992). Compared to nitrate, ammonia is usually a very minor component of plant available nitrogen. Dissolved inorganic nitrogen (DIN) is a measure of the nitrogen available to plants, and is the sum of the concentrations of nitrate-, nitrite- and ammonia-nitrogen.

Although nutrient availability is one of the major controlling factors in periphyton development, linking periphyton biomass to stream nutrient concentrations is very difficult (MfE, 2000). This is because of the complex interaction of other controlling factors such as flow regime, substrate and shading effects. In addition, because of plant uptake of dissolved nutrients, concentrations measured in water samples represent those surplus to plant requirements. For this study, both dissolved inorganic nutrient concentrations (DRP and DIN), cellular nutrient concentrations and conductivity values were investigated as indicators of the nutrient supply regime.

Despite the above limitations, water managers have traditionally used large amounts of resources collecting data on N and P concentrations in waters as indicators of the trophic status

of waterways. Therefore, various guidelines have been developed to assist water managers in setting nutrient target values for controlling plant growths in streams (e.g. MfE, 1992; MfE, 2000; ANZECC, 2000). Table 5.1 summarises the most recent guideline for dissolved nutrient concentrations to avoid proliferation of periphyton in New Zealand streams. These nutrient guidelines are based on varying flow regimes (average accrual periods). The average accrual period for the Waipara River is approximately 40 days (Table 2.1), and therefore, only the nutrient values relating to this accrual period are shown in Table 5.1.

Table 5.1 Nutrient guideline values predicted to prevent maximum biomass from exceeding given levels (MfE, 2000)

	Benthic biodiversity Chlorophyll *a* = 50 mg/m^2		**Aesthetic/recreational** Chlorophyll *a* = 120 mg/m^2 (filamentous) Chlorophyll *a* = 200 mg/m^2 (diatoms)	
Average days of accrual	DIN (annual mean)	DRP (annual mean)	DIN (annual mean)	DRP (annual mean)
40	<0.01 mg/L	<0.001 mg/L	<0.034 mg/L	<0.003 mg/L

The aim of this part of the investigation was to examine relationships between nutrient concentrations and periphyton biomass. It was hypothesised that spatial patterns in periphyton biomass are a function of nutrient availability. Nutrient availability is expected to increase downstream because of increasing land use intensity. It was therefore, hypothesised that periphyton biomass would also increase downstream as a function of increasing nutrients.

5.2 Results

5.2.1 Summary of nutrient data

Table 5.2 summarises the monthly nutrient data collected at the four monitoring sites on the Waipara River. Figure 5.1 and 5.2 show the variation in nutrient concentrations among the sites. Figure 5.1 includes data presented by Meredith & Hayward (2002) which they considered representative of the general state of upper and lower reaches of hill-fed rivers in Canterbury. These data allow comparisons to be made between the Waipara River and the general state of hill-fed Canterbury rivers. Sites 1 and 2 are classified by Meredith & Hayward (2002) as being part of the upper reaches of a hill-fed river, while sites 3 and 4 were on lower reaches.

In comparison to nutrient guidelines, overall mean concentrations of DIN in the Waipara River were well above the guideline values given for both aesthetic/recreational and biodiversity values. Similarly, the mean concentrations of DRP in the Waipara River at all sites were well above the guideline value of 0.001 mg/L for biodiversity. Mean DRP values at all sites were just above the aesthetic/recreational guideline values (Table 5.2).

The dissolved nutrient concentrations in the Waipara River showed a variable spatial pattern. DIN and DRP concentrations were generally lowest at the uppermost site, Site 1. A significant decrease in DRP concentrations occurred between sites 1 and 2, while DRP concentrations increased between sites 2 and 3 and showed no significant difference between sites 3 and 4 (Table 5.3, Figure 5.1). A converse spatial pattern was found with DIN concentrations in the downstream sites. DIN concentrations were generally lowest at Site 1, increased between sites 1 and 2, decreased between sites 2 and 3, and increased between sites 3 and 4 (Table 5.3, Figure 5.1).

In comparison to the general state for hill-fed rivers in Canterbury, dissolved nutrient concentrations in the Waipara River tended to be low. In particular, the range of DIN concentrations for sites 1 and 2, were lower than the general range of upper hill-fed Canterbury rivers. Similarly, for sites 3 and 4, the range of DIN concentrations were considerably lower than the general range for this type of river. Median DRP concentrations for the four sites were similar to the median values for upper reaches of hill-fed rivers. However, the range of DRP values was generally lower than those of upper and lower hill-fed rivers. In contrast, comparison of the conductivity values for the Waipara River, as an indicator of overall ionic content, showed much higher values than normally found in Canterbury hill-fed rivers (Figure 5.1). Also, there was consistent significant increase in conductivity values with distances downstream (Figure 5.1, Table 5.3).

Temporal patterns in dissolved nutrient concentrations showed increased DRP and DIN concentrations following flood events, and generally lower nutrient concentrations during low flows (Figure 5.3 and Figure 5.4). Correlation of nutrient data with daily mean flows showed a positive correlation between flows and DRP concentrations (Table 5.4). No significant correlation was found with DIN and flows, although a significant correlation occurred with total nitrogen concentrations and flows. Conductivity values in contrast, showed negative correlation with flows. Temporal patterns in conductivity values show a notable increase in conductivity values during periods of low flows (Figure 5.5).

Table 5.2 Summary of nutrient concentrations in water and periphyton samples collected monthly from four sites on the Waipara River

	% cellular N	% cellular P	Cellular N:P ratio	COND mS/s	NH_3N mg/L	NNN mg/L	DIN mg/L	DRP mg/L	DIN:DRP ratio	TN mg/L	TP mg/L
Site 1											
Mean	5.8	0.40	22.2	21.7	0.028	0.093	0.120	0.006	26.8	0.257	0.011
Geometric mean	4.1	0.26	15.8	20.4	0.017	0.032	0.061	0.004	14.2	0.204	0.008
Minimum	0.3	0.04	5.8	14	0.003	0.003	0.005	0.001	1	0.040	<0.008
Median	4.8	0.32	10.7	19	0.014	0.029	0.053	0.004	15	0.185	<0.008
Maximum	17.4	1.63	84.1	40	0.120	0.620	0.623	0.027	156	0.890	0.055
Count	19	19	19	31	30	30	30	30	30	30	30
Site 2											
Mean	8.5	0.63	16.0	27.6	0.049	0.130	0.179	0.005	58.4	0.303	0.011
Geometric mean	7.6	0.53	14.5	25.9	0.022	0.058	0.107	0.003	33.6	0.243	0.007
Minimum	3.6	0.13	5.8	17	0.003	0.003	0.005	0.001	1	0.040	0.004
Median	6.6	0.49	13.9	24	0.019	0.061	0.131	0.004	40	0.265	0.004
Maximum	16.6	1.51	45.1	51	0.450	0.660	0.666	0.015	233	0.880	0.058
Count	24	24	24	31	30	30	30	30	30	30	30
Site 3											
Mean	5.0	0.37	16.7	28.4	0.033	0.110	0.143	0.006	39.2	0.253	0.013
Geometric mean	4.6	0.33	14.2	27.3	0.021	0.042	0.079	0.004	19.5	0.198	0.008
Minimum	1.3	0.11	4.2	18	0.003	0.003	0.005	0.001	1	0.040	<0.008
Median	4.7	0.38	13.8	28	0.022	0.069	0.115	0.004	22	0.185	<0.008
Maximum	9.6	0.67	42.2	44	0.150	0.670	0.675	0.021	192	1.000	0.066
Count	21	21	21	31	30	30	30	30	30	30	30
Site 4											
Mean	7.8	0.52	16.6	34.5	0.042	0.248	0.290	0.006	76.6	0.434	0.012
Geometric mean	7.4	0.48	15.5	33.7	0.027	0.114	0.181	0.004	43.6	0.328	0.009
Minimum	2.5	0.14	8.2	24	0.003	0.003	0.005	0.001	1	0.090	<0.008
Median	7.7	0.52	15.2	34	0.028	0.160	0.217	0.005	47	0.325	0.009
Maximum	15.6	0.94	33.7	48	0.210	0.990	1.013	0.031	324	1.200	0.040
Count	25	25	25	31	30	30	30	30	30	30	30

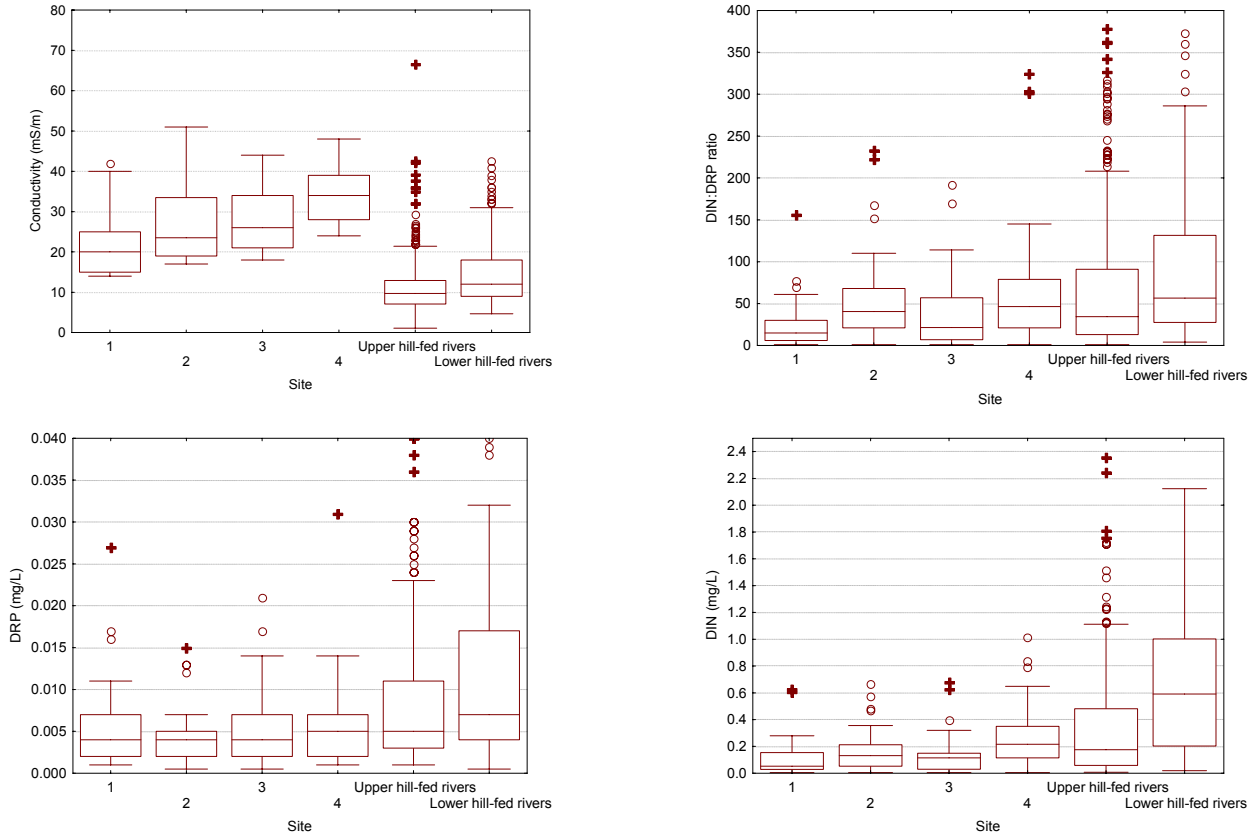

Figure 5.1 Comparison of conductivity, DIN:DRP ratios and DRP and DIN concentration at four sites on the Waipara River with upper and lower hill-fed rivers in Canterbury[3]

[3] Note: horizontal bar = median, box =interquartile range, whisker ends = 5 and 95 percentile, o and + indicate outlier and extreme values respectively

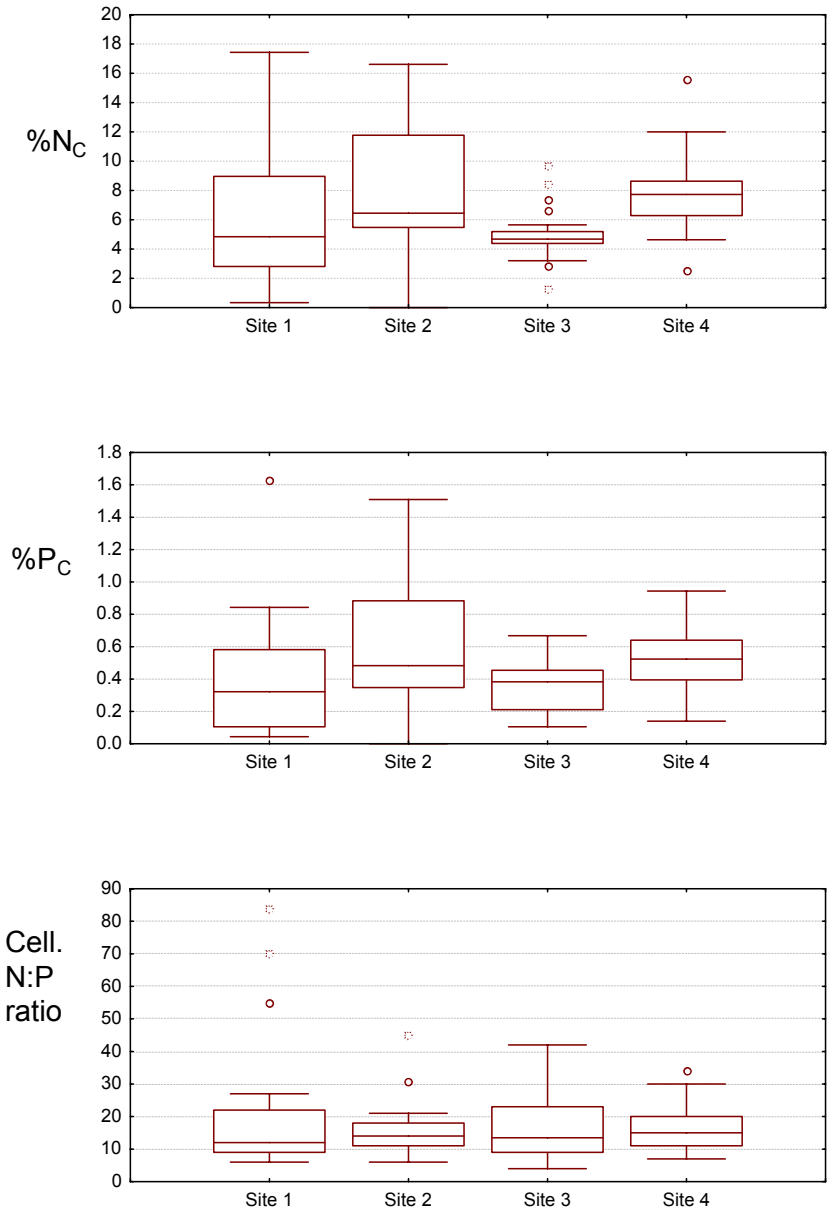

Figure 5.2 Comparison of percent cellular N and P values in periphyton at the four monitoring sites [4]

[4] Note: horizontal bar = median, box =interquartile range, whisker ends = 5 and 95 percentile, o and + indicate outlier and extreme values respectively

Table 5.3 Site comparison of monthly data for the Waipara River monitoring sites (two-tailed Wilcoxon Signed Rank test)

Upstream site Downstream site	Site 1 Site 2	Site 2 Site 3	Site 3 Site 4
Conductivity	*** ▲	* ▲	*** ▲
Ammonia nitrogen	ns	ns	* ▲
Nitrate/nitrite nitrogen	** ▲	* ∇	*** ▲
Dissolved inorganic nitrogen	** ▲	* ∇	*** ▲
Dissolved reactive phosphorus	* ∇	* ▲	ns
DIN/DRP ratio	*** ▲	* ∇	** ▲
Total nitrogen	ns	** ∇	*** ▲
Total organic nitrogen	ns	ns	* ▲
Total phophorus	ns	ns	ns
Ash-free dry mass	** ▲	** ∇	** ▲
Chlorophyll *a*	*** ▲	** ∇	** ▲
% N_C	ns	** ∇	** ▲
% P_C	ns	* ∇	* ▲
Cellular N:P	ns	ns	ns

ns = not significant

* = P <0.05

** = P <0.01

*** = P < 0.005

▲ = increase in determinand concentration at downstream site

∇ = decrease in determinand concentration at downstream site

Table 5.4 Spearman rank correlation values of water quality and periphyton biomass data for all four sites on the Waipara River (shaded cells – p <0.05)

	Flow	NH3N	$\%N_C$	$\%P_C$	AFDM	$N_C:P_C$	Chl. *a*	COND	DRP	NNN	DIN	DIN:DRP	TON	TN
NH3N	-0.429													
$\%N_C$	0.118	-0.035												
$\%P_C$	0.471	-0.035	0.661											
AFDM	-0.612	0.305	-0.064	-0.260										
$N_C:P_C$	-0.555	0.203	0.205	-0.508	0.371									
Chl. *a*	-0.530	0.296	0.185	-0.073	0.911	0.395								
COND	-0.741	0.453	0.067	-0.235	0.611	0.449	0.594							
DRP	0.277	0.041	0.067	0.075	-0.297	-0.030	-0.267	-0.127						
NNN	0.135	0.151	0.252	0.239	-0.092	0.094	-0.036	0.233	0.329					
DIN	0.088	0.378	0.158	0.222	-0.050	0.061	-0.008	0.251	0.276	0.916				
DIN:DRP	-0.087	0.342	0.113	0.158	0.146	0.092	0.174	0.324	-0.349	0.673	0.772			
TON	0.470	-0.452	0.120	0.118	-0.309	-0.146	-0.292	-0.367	0.278	0.120	-0.017	-0.165		
TN	0.366	-0.132	0.221	0.270	-0.213	-0.099	-0.175	-0.085	0.380	0.677	0.610	0.346	0.716	
TP	0.547	-0.137	0.143	0.319	-0.489	-0.269	-0.467	-0.311	0.420	0.071	0.078	-0.168	0.292	0.210

Cellular nutrient concentrations showed similar spatial patterns to the periphyton biomass values. The lowest median percent cellular N and P values occurred at sites 1 and 3, while the highest median values occurred at sites 2 and 4 (Figure 5.2). However, the range of values was greatest at sites 1 and 2, with the highest percent cellular N and P occurring at Site 1. Overall, percent cellular N positively correlated with percent cellular P, NNN and TN, although not with DIN (Table 5.4). Percent cellular P positively correlated with flow and DIN, negatively correlated with conductivity and showed no significant correlation with DRP concentrations.

Percent cellular nitrogen values below 5% and percent cellular P values below 0.5% are considered to indicate nutrient limitation (Biggs, 1995). Percent cellular N values above 5% are found in streams with intensive catchment development and/or extensive areas of nutrient rich basement rocks (MfE, 2000). The median percent cellular N values for the four sites on the Waipara River ranged from 4.7 to 7.7% (Table 5.2). These values indicate some degree of nutrient enrichment. The median percent cellular P values ranged from 0.32 to 0.52% indicating P may be limiting at times.

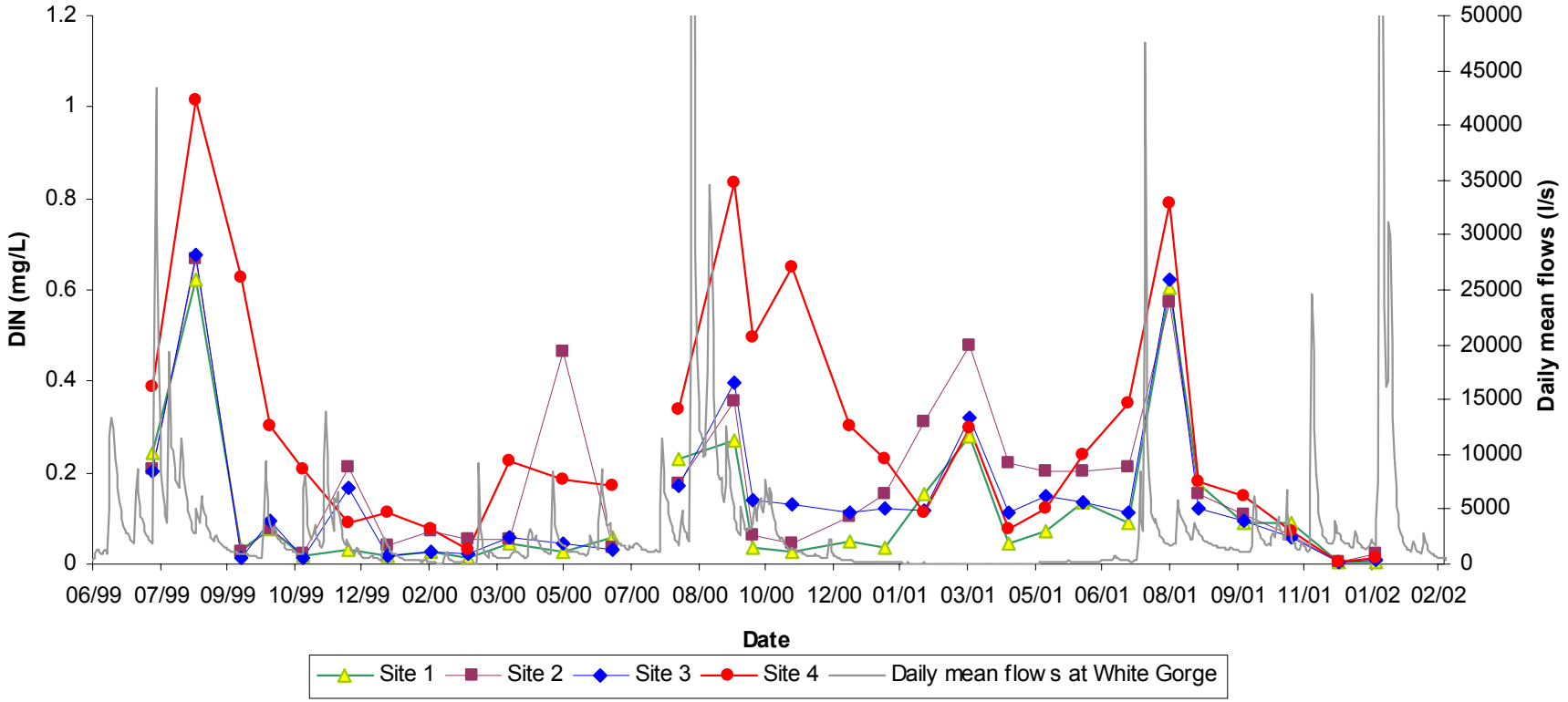

Figure 5.3 Temporal patterns in DIN concentrations at four sites on the Waipara River

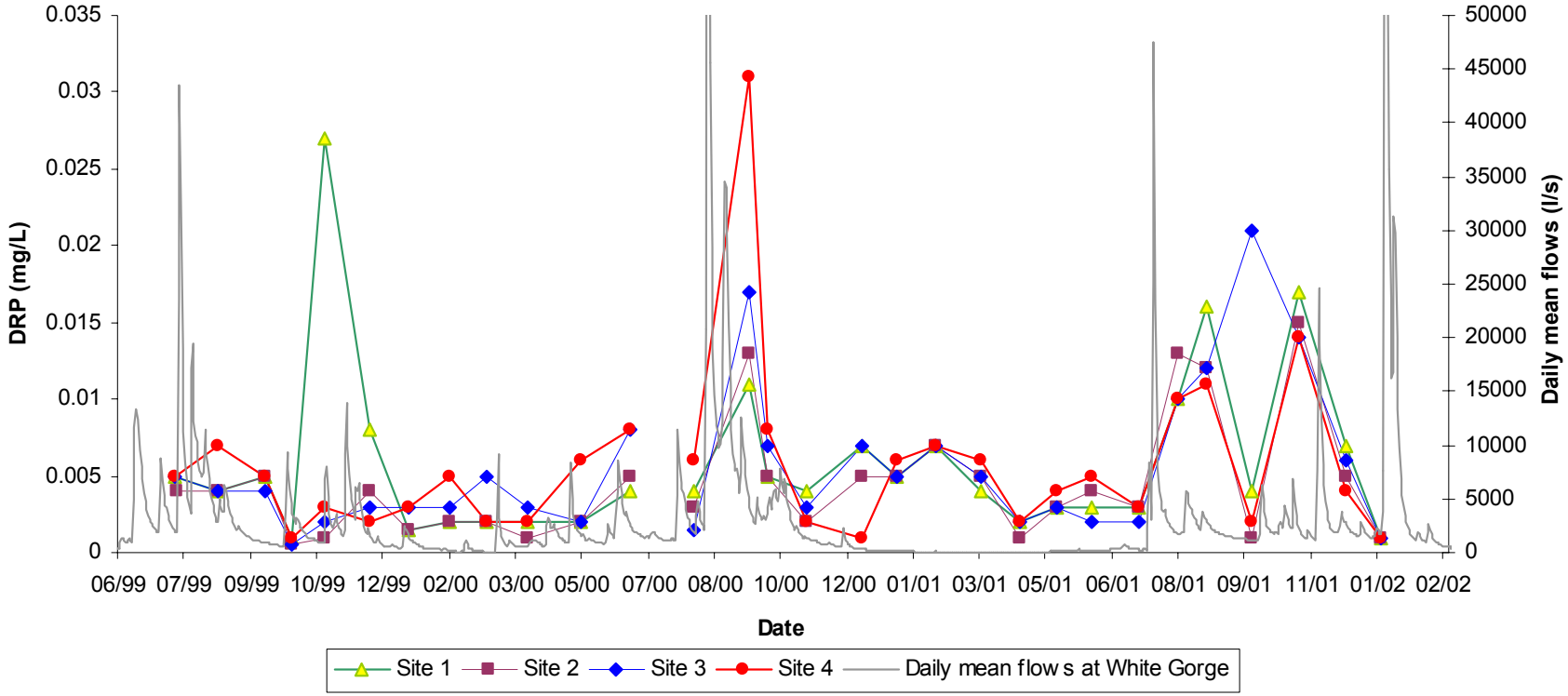

Figure 5.4 Temporal patterns in DRP concentrations at four sites on the Waipara River

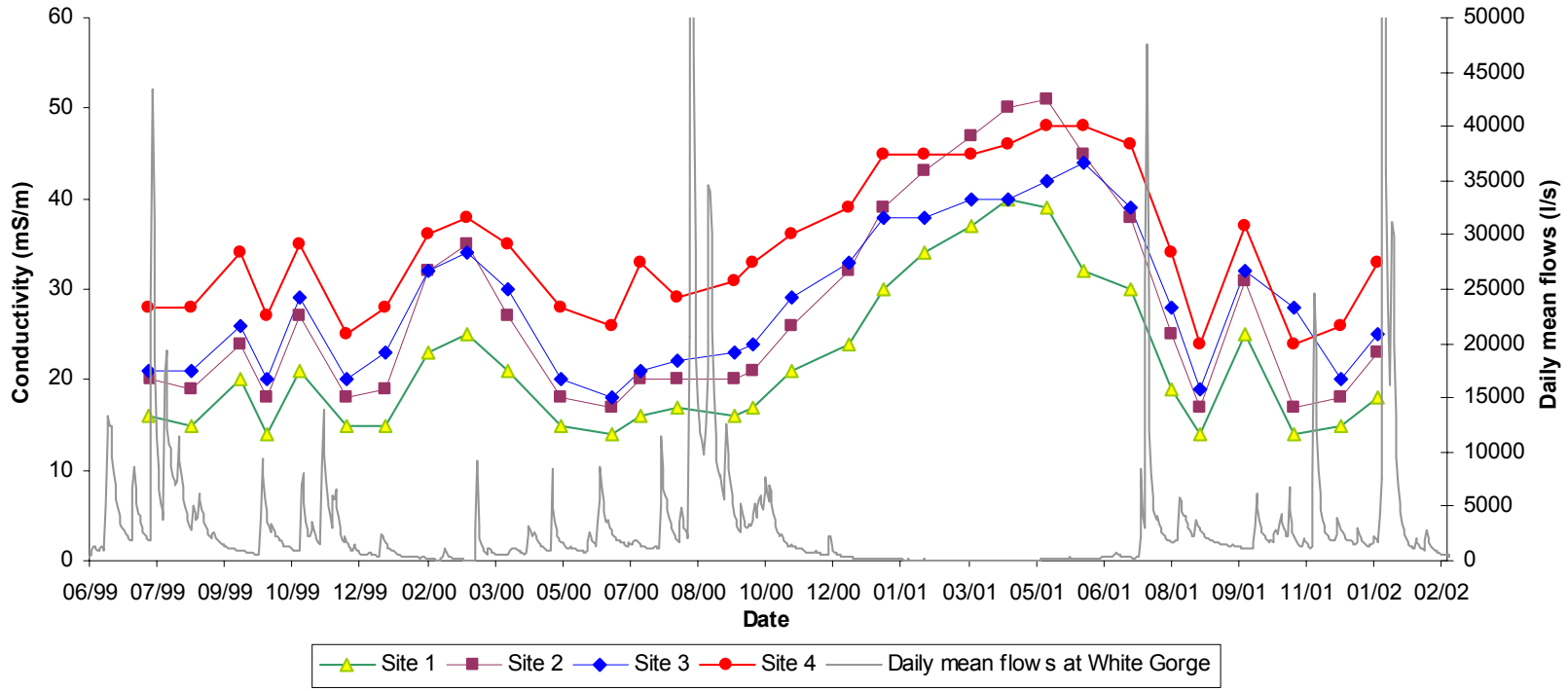

Figure 5.5 Temporal patterns in conductivity values at four sites on the Waipara River

Nitrogen to phosphorus ratios can indicate which nutrient might be limiting biomass development. However, this is only relevant if nutrient concentrations are low. Typically, ratios of less than 10:1 indicate that nitrogen is likely to be the limiting nutrient for algal growth and ratios greater than 20:1 indicate phosphorus will be limiting (Borchardt, 1996). Median cellular N:P ratios ranged from 10.7 at Site 1 to 15.2 at Site 4, indicating overall neither nutrient was strongly limiting for algal growth. However, Table 5.5 shows that at times of peak biomass, periphyton growth was limited by P availability at sites 1 and 4 as indicated by low $\%P_C$ and high N:P ratios. At Site 2, neither nutrients were strongly limiting, while both N and P may be somewhat limiting at Site 3 at times of peak biomass.

Dissolved nutrient N:P ratios generally showed higher values than the cellular N:P ratios (Table 5.2). Median DRP:DIN ratios ranged from 15 to 40. In comparison to the general state of hill-fed rivers in Canterbury, sites 1 and 3 had generally lower dissolved N:P ratios, while sites 2 and 4 had similar median values to lower reaches of hill-fed rivers in Canterbury. However, many hill-fed rivers had some very high values, which were not found in the Waipara River samples.

Correlation of biomass data with nutrients showed positive correlations of AFDM and chl. *a* values with conductivity, and negative correlations with DRP values (Table 5.4). AFDM values negatively correlated with $\%P_C$, but otherwise, biomass measurements did not correlate with cellular nutrient values or DIN concentrations.

Table 5.5 Percent cellular nutrient concentrations at time of low flow peak biomass (maximum chl. *a* values)

	Site 1 May 01	Site 2 Jan 01	Site 3 June 01	Site 4 Feb 01
$\%\ N_C$	5.2	5.9	3.2	4.7
$\%\ P_C$	0.07	0.43	0.23	0.14
N_C:P_C	70	14	14	34
Chl. *a* (mg/m^2)	54	325	455	331

5.2.2 Effects of nutrient supply on periphyton biomass

In order to examine the relationship between nutrient supply and periphyton biomass, annual average dissolved and cellular nutrient concentrations were compared to annual mean and maximum biomass measurements. The data collected monthly in the Waipara River was reduced to the same twelve month periods (Oct/99 to Sept/00 and Oct/00 to Sept/01) used in the following chapter (Chapter 6 – River flows). This also allowed the interaction of nutrients and flow regimes to be examined.

The trophic status of the four sites on the Waipara River in terms of nutrient concentrations and accrual periods is plotted in Figure 5.6. This nomograph depicts maximum chl. *a* boundaries of 60 mg/m^2 and 200 mg/m^2 to delimit oligotrophic, mesotrophic and eutrophic streams based on annual mean dissolved nutrients for different periods of accrual (MfE, 2000). Annual DIN concentrations during the 99/00 year indicate nutrient concentrations at sites 1 and 3 were at the mesotrophic/eutrophic boundary, while sites 2 and 4 were just above that boundary. During the 00/01 year, a small increase in average DIN concentrations and a much longer average accrual period put all sites well into the eutrophic status. A similar pattern occurred with the DRP concentrations, except that all sites plotted as being mesotrophic during the 99/00 year.

Figure 5.7 shows the annual maximum chl. *a* values versus the annual average accrual period[5] for the two years data. As predicted by DIN concentrations (Figure 5.6), the maximum chl. *a* values for sites 2 and 4 were at or above the mesotrophic/eutrophic boundary for the 99/00 year. However, maximum 99/00 biomass for sites 1 and 3 was lower than might be predicted from the dissolved nutrient data and plotted near the oligotrophic/mesotrophic boundary. Maximum biomass values for sites 2, 3 and 4 during the 00/01 year were indicative of eutrophic conditions, while the maximum biomass at Site 1 during 00/01 was similar to the previous year and plotted on the oligotrophic/mesotrophic boundary.

[5] Annual average accrual period was calculated as the average number of days between flood events exceeding 3 x median flow, excluding accrual periods of less than 6 days duration.

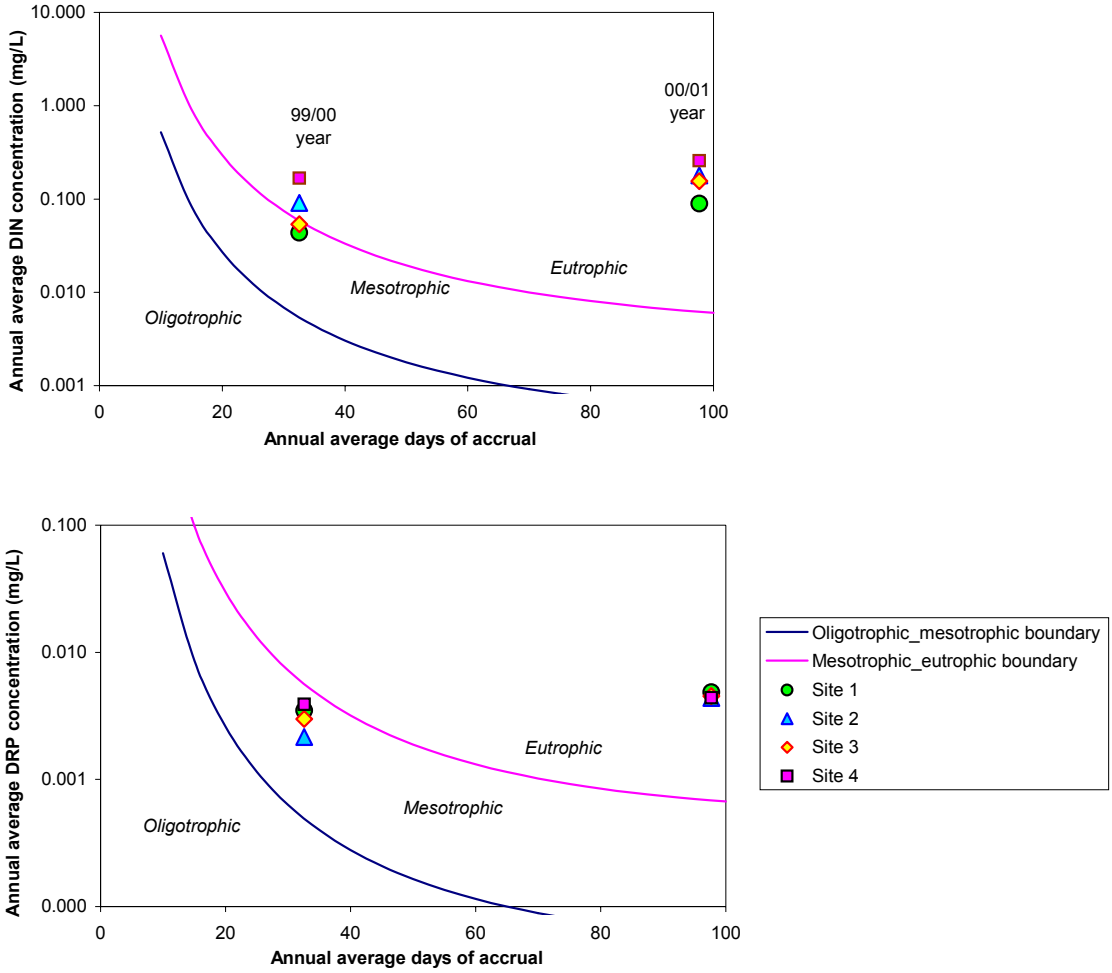

Figure 5.6 **Trophic designation of sites on the Waipara River based on annual average nutrient data for 99/00 and 00/01 periods. The graphs show trophic boundaries calculated from regression equations combining days of accrual and mean monthly dissolved nutrient concentrations predicting annual maximum biomass expected at the defined trophic levels (MfE, 2000). Trophic boundaries based on maximum chl. *a* are: <60 mg/m^2 - oligotrophic, 60 to 200 mg/m^2 - mesotrophic, >200 mg/m^2 - eutrophic.**

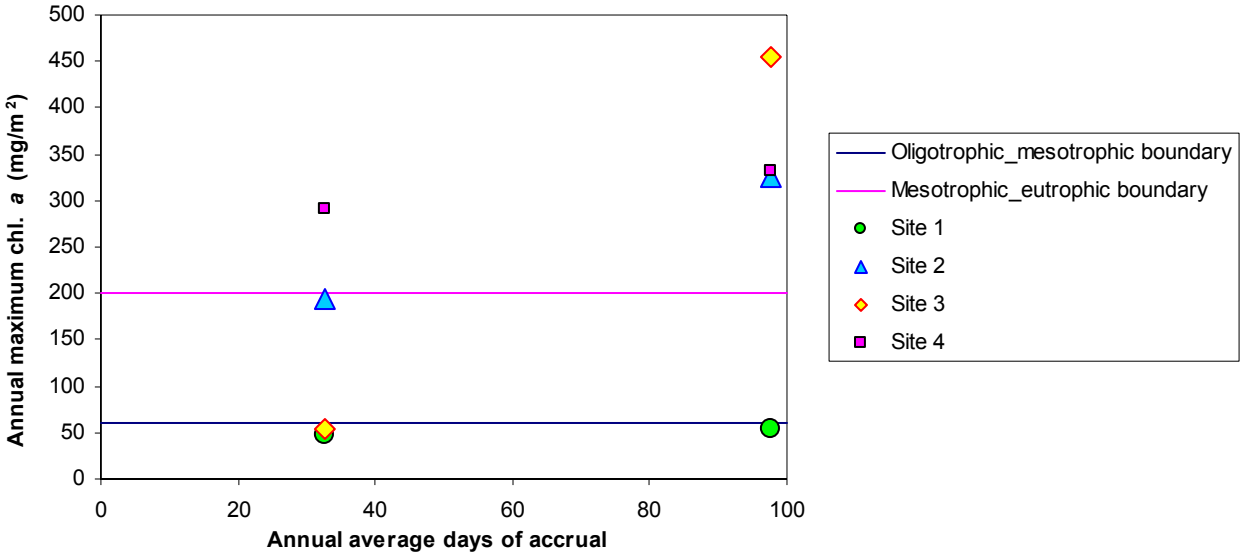

Figure 5.7 Annual maximum chl. *a* values as a function of annual average accrual days. Trophic boundaries are as described in Figure 5.6.

Table 5.6 summarises regression analyses of biomass and nutrient concentrations. Figure 5.8 depicts the relationship between annual mean nutrient concentrations (both dissolved and cellular) and annual mean chl. *a* and AFDM values.

Dissolved inorganic nitrogen explained a significant proportion (67 to 82%) of variation in annual mean and maximum chl. *a* and AFDM values (Table 5.6). Similarly, conductivity explained between 61 to 82 % of variation in annual mean and maximum biomass values. Regression analyses of mean and maximum biomass values as a function of DRP and cellular nutrients were not statistically significant. These relationships are shown in Figure 5.8. Conductivity showed a statistically significant positive correlation with biomass measurements. Similarly, annual biomass measurements increased with increased annual DIN concentrations. However, relationship of chl. *a* and AFDM with DIN at Site 4 is offset compared to the other sites.

Table 5.6 Regression analysis of mean and maximum biomass data as a function of annual mean nutrient concentrations (data was log transformed prior to regression analysis)

	Effect	Value/ coefficient	SE	p (2-tail)	r^2
Annual mean Ln chl. a	Constant	3.662	10.416	0.737	
	Ln DRP	-0.03	1.978	0.988	0
	Constant	7.606	0.745	0.000	
	Ln DIN	2.062	0.393	0.002	0.821
	Constant	5.052	1.446	0.013	
	Ln $\%P_C$	1.594	1.801	0.410	0.116
	Constant	-0.588	3.089	0.855	
	Ln $\%N_C$	2.354	1.637	0.200	0.256
	Constant	-7.661	2.867	0.037	
	Ln conductivity	3.435	0.855	0.007	0.729
Annual mean Ln AFDM	Constant	2.9	6.774	0.683	
	Ln DRP	0.048	1.286	0.971	0
	Constant	5.155	0.441	0.000	
	Ln DIN	1.366	0.233	0.001	0.851
	Constant	3.155	0.977	0.018	
	Ln $\%P_C$	0.657	1.216	0.608	0.046
	Constant	-0.126	2.031	0.953	
	Ln $\%N_C$	1.48	1.077	0.218	0.24
	Constant	-5.29	1.505	0.013	
	Ln conductivity	2.375	0.449	0.002	0.823
Annual max. Ln Chl. *a*	Constant	4.097	8.901	0.662	
	Ln DRP	-0.183	1.69	0.917	0.002
	Constant	8.12	0.777	0.000	
	Ln DIN	1.677	0.411	0.007	0.733
	Constant	5.897	1.267	0.003	
	Ln $\%P_C$	1.085	1.577	0.517	0.073
	Constant	2.054	2.803	0.491	
	Ln $\%N_C$	1.605	1.486	0.322	0.163
	Constant	-3.961	2.923	0.224	
	Ln conductivity	2.699	0.872	0.021	0.615
Annual max. Ln AFDM	Constant	7.159	6.262	0.297	
	Ln DRP	0.679	1.189	0.589	0.052
	Constant	5.704	0.619	0.000	
	Ln DIN	1.154	0.327	0.012	0.675
	Constant	3.829	0.944	0.007	
	Ln $\%P_C$	0.316	1.175	0.797	0.012
	Constant	1.266	1.995	0.549	
	Ln $\%N_C$	1.238	1.057	0.286	0.186
	Constant	-3.656	1.663	0.070	
	Ln conductivity	2.166	0.496	0.005	0.761

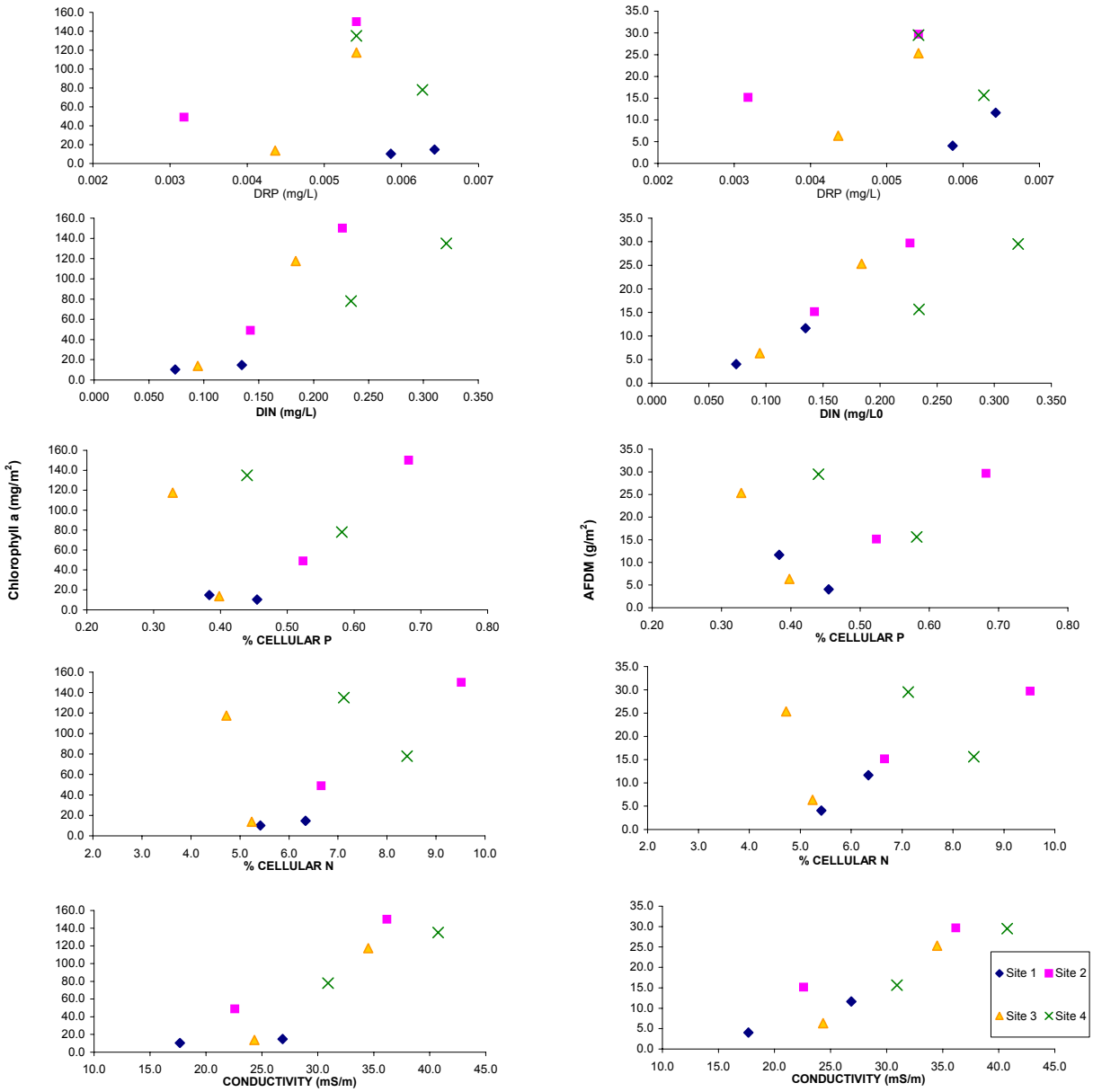

Figure 5.8 Relationship between mean annual biomass measurements and annual mean nutrient concentrations for the 99/00 and 00/01 year periods.

5.2.3 Community composition and nutrient status

Table 4.5 in Chapter 4 includes the inorganic trophic designation of a limited number of algal species commonly found in the Waipara River based on MfE (2000). Not all of the main species have been designated to a particular trophic habitat. This is because of the uncertainty about the distribution of some species and because some species occur in abundance in a wide range of habitats (Biggs & Kilroy, 2000). The main species found at all sites covered a range of enrichment habitats. *Cymbella kappii* and *Gomphoneis minuta* var. *cassieae*, which were commonly found at all sites, are associated with oligotrophic to mesotrophic habitats. Similarly, *Melosira varians*, which is associated with mesotrophic to eutrophic habitats was commonly found at all sites. However, *Cladophora glomerata*, which is commonly associated with eutrophic habitats, was the 5th and 7th most abundant species at sites 2 and 4 respectively. *C. glomerata* was the 12th most abundant species found at Site 3, but was very rarely found at Site 1.

Table 5.7 shows the main species (relative abundance of 6 or greater) found at the time of maximum biomass for the entire monitoring period. At all sites, the maximum biomass occurred during the low flow period of January to July 2001, although the peaks occurred at different time within this period at each site. At all sites the peak in biomass was followed by a marked decrease in biomass caused either by autogenic sloughing or grazing but not by flood disturbance. Therefore, the community composition could be considered to be representative of a mature community and be reflective of the site habitat. At Site 1 the dominant species are indicative of oligotrophic to mesotrophic habitats, which is consistent with biomass and nutrient data for this site (Table 5.7). *Cocconeis pediculus*, *S. ulna* var. *biceps* and *C. glomerata* were the dominant species at the other three sites, although their relative abundances differed among sites. These species can be considered indicative of eutrophic habitat conditions.

Table 5.7 Summary of the dominant taxa (relative abundance score in brackets) found in samples collected at the time of peak biomass.

Site 1		Site 2		Site 3		Site 4	
Main taxa	**TD**	**Main taxa**	**TD**	**Main taxa**	**TD**	**Main taxa**	**TD**
Epithemia sorex (8)	O-M	*Cocconeis pediculus* (8)	M-E*	*Synedra ulna* var. *biceps* (8)	E*	*Synedra ulna* var. *biceps* (8)	E*
Rhopalodia novae-zealandiea (6)	O	*Synedra ulna* var. *biceps* (8)	E*	*Cladophora glomerata* (7)	E	*Cocconeis pediculus* (7)	M-E*
		Cladophora glomerata (7)	E	*Cocconeis pediculus* (6)	M-E*	*Cladophora glomerata* (6)	E

TD - trophic designation: O-oligotrophic, M-mesotrophic, E-eutrophic (MfE, 2000)

* - common habitat inferred from Biggs and Kilroy's (2000) identification guide

5.3 Discussion

Dissolved nutrient concentrations were generally lower at the four monitoring sites compared to the general state of hill-fed rivers in Canterbury. This contrasts with the nutrient enriched trophic status indicated by the moderate to high periphyton biomass at sites 2, 3 and 4. Similar results were found by Suren *et al*. (2003a), when they compared periphyton biomass and water nutrient status between the Waipara River and the Okuku River during a period of low stable flows. They found a very high periphyton biomass occurred in the Waipara River compared to the Okuku River, while the dissolved nutrient concentrations in the Okuku River were higher than those of the Waipara River.

These results reflect the difficulty in assessing nutrient supply regimes of streams, where plant uptake of nutrients can result in low dissolved nutrient concentrations (MfE, 2000, Biggs, 2000). The dissolved nutrients measured in water samples represent those surplus to plant requirements. In streams such as the Waipara River, which have typically moderate to high biomass, dissolved nutrient concentrations can be significantly altered by plant uptake.

The cellular nutrient data for sites 2 and 4 showed a general state of enrichment with the geometric means of $\%N_C$ for both these sites being well above 5% and $\%P_C$ being near or above 0.5%. Nitrogen enrichment was particularly apparent at these sites. Cellular nutrient

data indicated Site 1 was moderately enriched with nitrogen, but probably limited by phosphorus availability. Similarly, Site 3 was overall moderately enriched with nitrogen and at times limited by phosphorus. At times of peak biomass, sites 1, 3 and 4 were probably moderately to severely limited by phosphorus. Neither N nor P appeared to be limiting at Site 2.

Moderate concentrations of dissolved phosphorus are expected in the Waipara River because of the presence of marine tertiary sediments in parts of the catchment. In particular, these sediments are present in significant amounts in the local catchment above sites 2 and 4 (Wilson, 1963). Phosphate deposits are present within, and adjacent to, the limestone sediments, which can become dissolved into water passing through these sediments (Wilson, 1963). This is consistent with the percent cellular P values being generally highest at sites 2 and 4, although this is not the case for DRP concentrations. With the moderate to high biomass that occurs at these sites, it appears the available dissolved phosphorus is rapidly taken up by the algae, resulting in moderately low DRP concentrations.

Cellular N data indicated generally enriched conditions at sites 2 and 4. Moderate to high values also occurred at Site 1 on occasions. Sources of nitrogen in the Waipara catchment include fertiliser use and grazing stock on surrounding land (Lloyd, 2002). In addition, the presence of marine tertiary sediments, while not a direct source of nitrogen, can contribute to increased nitrogen turnover in soils overlying these sediments, which could in turn result in increased release of nitrogen to the river system (Biggs & Gerbeaux, 1993).

While moderately intensive land-use occurs in the lower parts of the Waipara River catchment, the river is somewhat isolated from the surrounding land. In particular the upper and lower gorges provide a wide buffer between the river system and surrounding land. Surface run-off from rainfall is probably one of the main mechanisms by which land use activities impact on the nutrient status of the river. This is observed in the DIN and DRP concentrations, which tend to be highest following flood events. However, even during periods of low flows, high DIN values are observed at Site 1 and to a lesser extent at Site 2. This may be the result of localised effects of stock access to riverbed. During several sampling occasions, it was noted particularly at Site 2 that sheep were permitted to graze the river bed, presumably in part because of water supply shortages during summer dry periods. Cattle have also been observed grazing the riverbed of tributaries above Site 4. Because of the low flows in the river during these periods, any addition of nutrients from animal faeces and urine may have an impact on

the nutrient concentrations because of the lack of dilution capacity of the river. This may well be the reason for the unusually high DIN concentrations found during the 00/01 summer at Site 2.

During periods of low flows, the concentrations of phosphates and other major ions will increase because of lack of dilution from lower ionic content water. This is apparent in the conductivity values which show a strong negative correlation with water flows. Conductivity values have been successfully used as a surrogate for assessing the supply of nutrients, and are highly correlated to periphyton biomass (Biggs, 1990, 1995). This is because the major ions (e.g. calcium, sodium, bicarbonate and chloride), which are largely unused by plants, are leached from the rocks and soils in the same proportion to plant nutrients. These ions remain in the water, even though the nutrients have been taken up by plants, and are the major contributors to water conductivity values.

The uptake of dissolved nutrients by periphyton is likely to be one of the main reasons for low concentrations of DIN and DRP generally found during summer and autumn. High nutrient concentrations found following floods results from both nutrients in run-off water during rainfall as well as the absence of periphyton to utilise nutrients.

The strong positive correlation between conductivity and AFDM and chl. *a* values concurs with other studies demonstrating the usefulness of conductivity as an indicator of inorganic enrichment and biomass potential (e.g. Biggs & Price, 1987; Biggs & Close; 1989; Biggs, 1995). Conductivity also explained a significant proportion of the variation in annual mean and maximum biomass measurements at the four sites on the Waipara River.

The conductivity values were also negatively correlated with flows. Therefore, the relationship between conductivity and biomass also incorporated an element of the flow regime of the river. Conductivity values, both between sites and as a result of different flow regimes, provided a useful indicator of nutrient inputs. However, the overall spatial pattern in conductivity values did not reflect spatial pattern in biomass (compare Figure 4.1 with Figure 5.1). This suggests other factors may also be controlling biomass development at the local scale.

DIN values were also strongly linked to maximum and average biomass values. This suggest that long-term (yearly) patterns in biomass may be controlled by nitrogen inputs to the river

system. However during some low flows periods, phosphorus limitation appears to control growth at Site 1, and possibly at Site 3.

The community composition during periods of low flows, when communities had time to mature reflected strongly the nutrient status of each site. In particular, the high relative abundance of the filamentous green algae C*ladophora glomerata* at sites 2, 3 and 4 during low flow periods is consistent with many studies of enriched waters where this species dominates (e.g. Freeman, 1986; Biggs & Price, 1987; many references cited in Steinman, 1996). The dominance of *Epithemia sorex*, which contains a nitrogen fixing symbiotic cyanobacteria, at Site 1 may indicate nitrogen limitation at this site.

6 River flows

6.1 Introduction

Flow regimes are recognised as a major controlling factor in the development of stream periphyton (Biggs, 1996, MfE, 2000). Water velocities, frequency of disturbance events (floods) and duration of periods of stable flows are all factors influencing the spatial and temporal patterns in periphyton biomass and composition (Clausen & Biggs, 1997).

Floods result in biomass loss through shear stress, abrasion by suspended sediments and scouring by substrate movement. The susceptibility of periphyton to flood disturbance varies widely depending on the size of the flood and the nature of the substrate material (Horner *et al*., 1990; Biggs & Thomsen, 1995; Biggs *et al.*, 1999a). Substrate movement may be the major mechanism of biomass loss of thin periphyton films, while shear stress and abrasion from high velocity and dissolved sediments result in loss of moderate to thick growths of periphyton (Duncan & Biggs, 1998). In an experimental flow chamber, Horner *et al.* (1990) found that the combination of increased suspended sediment and water velocity resulted in greater biomass loss than when only one variable was increased. However, periphyton resistance to the effects of floods also depends on biomass, taxonomic structure and physiological state of the pre-flood community (Biggs & Close, 1989; Biggs & Thomsen, 1995; Biggs *et al.*, 1999b).

Increases in flows can also have a stimulatory effect on algal growth (Stevenson, 1996). Several studies have documented increases in biomass with increased water velocities up to a point where shear stresses result in biomass loss (e.g. Horner *et al,*. 1990; Biggs & Stoketh, 1996; Biggs, *et al.*, 1999b). Increases in water velocities reduce the thickness of the laminar boundary around cells, increasing the rate of nutrient supply and export of waste metabolites. The stimulatory effect of increased water velocities only occurs up to a point, where shear stresses become a negative controller of biomass (Stevenson, 1996). The optimum water velocity differs among species, as does the effect of shear stress on biomass loss.

During periods of low stable flows a succession of periphyton community development is expected. As river flows recede during summer in nutrient-enriched rivers, there is often a shift in periphyton community from a low growing, diatom dominated community to that dominated by filamentous green algae (e.g. Biggs & Price, 1987; Suren *et al.,* 2003a).

While flow regimes of rivers have been shown to be a major controlling factor in periphyton development, defining a biologically significant measure of flow variability and disturbance events in temperate streams has been difficult. Clausen & Biggs (1997) analysed data from hydrological records and monitoring data of benthic biota from 83 New Zealand rivers to identify the most ecologically relevant hydrological indices. They found the frequency of flood events of magnitude at least three times greater than median flow (FRE_3) to be the most ecologically useful overall flow variable. The FRE_3 flow statistic allows comparison of flood frequency between rivers, and therefore, provides an index of disturbance regimes on stream biota. This can be useful for assessing impacts of water abstraction or flow regulation on stream ecosystems (MfE, 1998). The New Zealand guidelines for the management of periphyton use FRE_3 as a basis for classifying flow regimes of rivers for determining nutrient guideline values (MfE, 2000).

The aim of this part of the study was to examine the interaction of the flow regime of the Waipara River with periphyton growth. In particular, the effects of low stable flows on periphyton development are studied. It was hypothesised that during periods of low stable flows, prolific periphyton biomass would develop. Furthermore, filamentous algal growth would become increasingly abundant with increasing duration of stable flows.

The following aspects of flow interaction with periphyton development were examined:

- definition of flows at which significant loss of biomass is expected
- the relationship between accrual periods and maximum biomass and rate of growth among the sites
- medium term (annual) patterns in biomass as a function of frequency of floods
- development of algae during periods of stable flows

6.2 Results

6.2.1 Defining disturbance events

While FRE_3 provides a useful measure of the variability in flows among streams, it may not be applicable in the Waipara River for defining bed flushing events, as the river has a low median flow of approximately 1000 l/s. At flows of 3000 l/s the mean water velocity is around 0.6 m/s (determined from flow gauging data for the White Gorge flow monitoring site, ECan unpublished data). Water velocities above 0.8 m/s are generally required for significant

biomass loss (Biggs & Close, 1989, Horner *et al*., 1990). Therefore, floods in the Waipara River which only reach 3000 l/s will not necessarily result in significant removal of periphyton.

Monthly chl. *a* data was examined to determine the magnitude of a flood event required to result in significant biomass loss for the Waipara River. Table 6.1 shows the percent change in biomass following flood events. The percent change of biomass was calculated from the difference in chl. *a* data between monthly samples, where a flood of at least 3000 l/s had occurred within no more than 14 days prior to collection of the second sample. A maximum period of 14 days was selected so that the change in biomass was not overly affected by growth following the flood.

Both positive and negative changes in biomass occurred following floods (Table 6.1). Positive values indicated biomass accrual between sampling occasions while negative values indicated a loss of biomass. Both loss and gain of biomass occurred with floods of between 4000 l/s to 9000 l/s. Even with a flood of 8600 l/s, a 10-fold increase in biomass occurred between sampling occasions. This could in part reflect rapid growth following the flood event (9 days prior to sampling). However, this flood occurred during winter (June 2000) when rates of growth are not expected to be high. Therefore, it is likely the periphyton communities at this time were resistant to scouring from a flood of this magnitude.

Only loss of biomass was observed following floods with peak mean daily flows of at least 9000 l/s. Biomass loss of between 80-100 % generally occurred for events of at least this magnitude. However, a sample collected at Site 1 four days after a flood of 9300 l/s yielded a moderate chl. *a* biomass of 47 mg/m^2. The pre-flood chl. *a* value for this site was 51 mg/m^2, indicating little biomass was lost during the flood at this site. This suggests that even at floods of this magnitude, some periphyton communities were resistant to scouring.

The above results suggest that floods of up to 10 000 l/s can have varying effects on biomass, but floods above this flow have a catastrophic effect on periphyton biomass. Environment Canterbury's flow gauging data showed that flows above 10 000 l/s have an average channel velocity of at least 1 m/s. Therefore, floods of 10 000 l/s have been used to define major disturbance events in this study. Days of accrual were calculated as the number of days since the last flood of at least this magnitude.

Table 6.1 Changes in periphyton biomass (chl. *a*) following flood events. Shaded cells indicate biomass loss.

Flood peak daily mean flow (l/s)	No. days sampled after flood	Sample date post flood	Site	Chl. *a* before flood (mg/m^2)	Chl. a after flood (mg/m^2)	Percent change in biomass
12620	6	20/09/00	Site 2	24	0.3	-99
			Site 3	7	0.3	-96
			Site 4	18	0.3	-98
11525	12	09/08/00	Site 1	8	0.3	-96
			Site 2	124	24	-81
			Site 3	11	7	-36
			Site 4	292	18	-94
11403	10	16/08/99	Site 1	4	0.3	-93
			Site 2	38	0.3	-99
			Site 3	3	0.3	-90
			Site 4	97	0.3	-100
9307	4	11/10/99	Site 1	51	47	-8
			Site 2	69	5	-93
			Site 3	20	1	-95
			Site 4	64	8	-88
8639	9	22/06/00	Site 1	2	35	1650
			Site 2	38	194	411
			Site 3	1	54	5300
			Site 4	23	75	226
8365	7	15/05/00	Site 1	10	2	-80
			Site 2	68	38	-44
			Site 3	9	1	-89
			Site 4	184	23	-88
6801	4	08/11/01	Site 1	0.3	0.5	67
			Site 2	52	17	-67
			Site 3	10	2	-80
			Site 4	66	88	33
6539	8	08/12/99	Site 1	6	3	-50
			Site 2	10	7	-30
			Site 3	3	5	67
			Site 4	94	91	-3
5816	14	09/08/01	Site 1	30	0.3	-99
			Site 2	83	0.3	-100
			Site 3	71	0.3	-100
			Site 4	110	0.3	-100
5533	14	30/08/01	Site 2	0.3	2	567
			Site 4	0.3	47	15567
5229	8	03/10/00	Site 1	0.3	4	1233
			Site 2	0.3	6	1900
			Site 4	0.3	9	2900
4407	14	02/11/00	Site 1	4	36	800
			Site 2	6	95	1483
			Site 3	0.3	9	2900
			Site 4	9	124	1278
3905	3	13/12/01	Site 1	0.5	1	100
			Site 2	17	11	-35
			Site 3	2	0	-100
			Site 4	88	94	7

6.2.2 Biomass as a function of accrual periods

The relationships between accrual periods and biomass measurements are shown in Figure 6.1 and 6.2. Chlorophyll *a* values were generally low (less than 60 mg/m^2) for accrual periods up to 50 days at Sites 1, 2 and 3. However, at Site 4, moderate biomass occurred within much shorter accrual periods. Moderate chl. *a* values of 91 and 94 mg/m^2 occurred after 17 and 18 days of accrual respectively at Site 4. These samples were collected in December 1999 and December 2001. It is expected that given the size of floods prior to these samples being collected (peak flood of ~14 m^3/s in Nov 99 and 24 m^3/s in Nov 01) that rapid growth rates rather than community resistance are likely reasons for these moderately high biomass values. Ash-free dry mass values were similarly low (<10 g/m^2) for accrual periods of less than 45 days at sites 1 and 3. Higher values occurred after shorter accrual periods at sites 2 and 4.

The guideline value for chl. *a* of 200 mg/m^2 was exceeded after 45 days of accrual at Site 2 on one occasion. However, in general, over 100 days of accrual were required to reach this level of nuisance growth. Similarly, AFDM measurements of over 35 g/m^2 occurred occasionally after 50 days of accrual, but generally higher values occurred after 100 days. The percent cover of thick mats exceeding the guideline value of 60% occurred after about 50 days accrual sites 1 and 3, and after 70 days at sites 2 and 4 (Figure 6.3). The percent cover of filamentous algae exceeding the guideline value of 30% occurred only at sites 2 and 3 (Figure 6.4). Site 2 exceeded this guideline value after 45 days accrual, while Site 3 exceeded the guideline only after 200 days of accrual.

Rates of growth were generally more rapid at sites 2 and 4 than the other two sites. The time taken to reach peak biomass was generally shortest at these sites (at around 150 to 200 days). At sites 1 and 3, time to peak biomass was generally greater than 250 days of accrual. Sites 2, 3 and 4 all showed signs of declining biomass at prolonged periods of accrual (300 days).

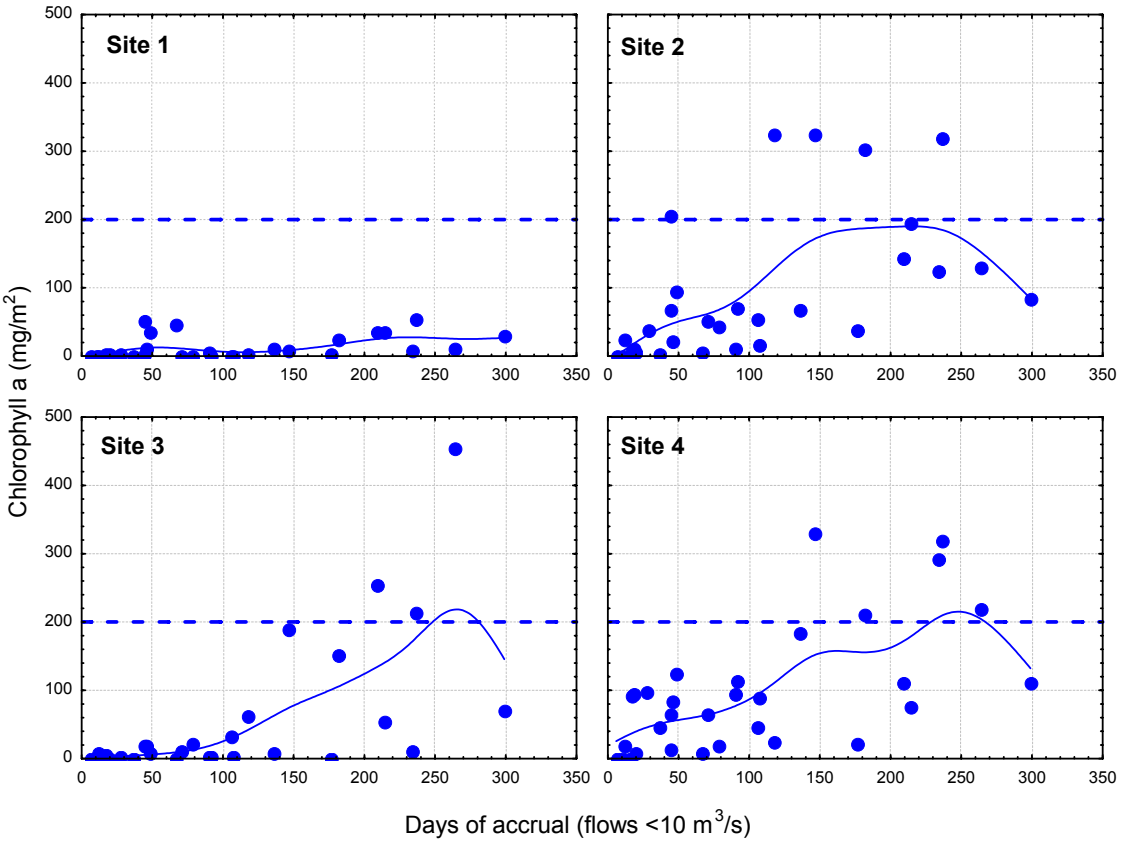

Figure 6.1 **Relationship between days of accrual and chl. *a* measurements. The line of best fit was determined using distance weighted least squares regression (Statsoft, 2002). The dashed line is the periphyton guideline value (MfE, 2000).**

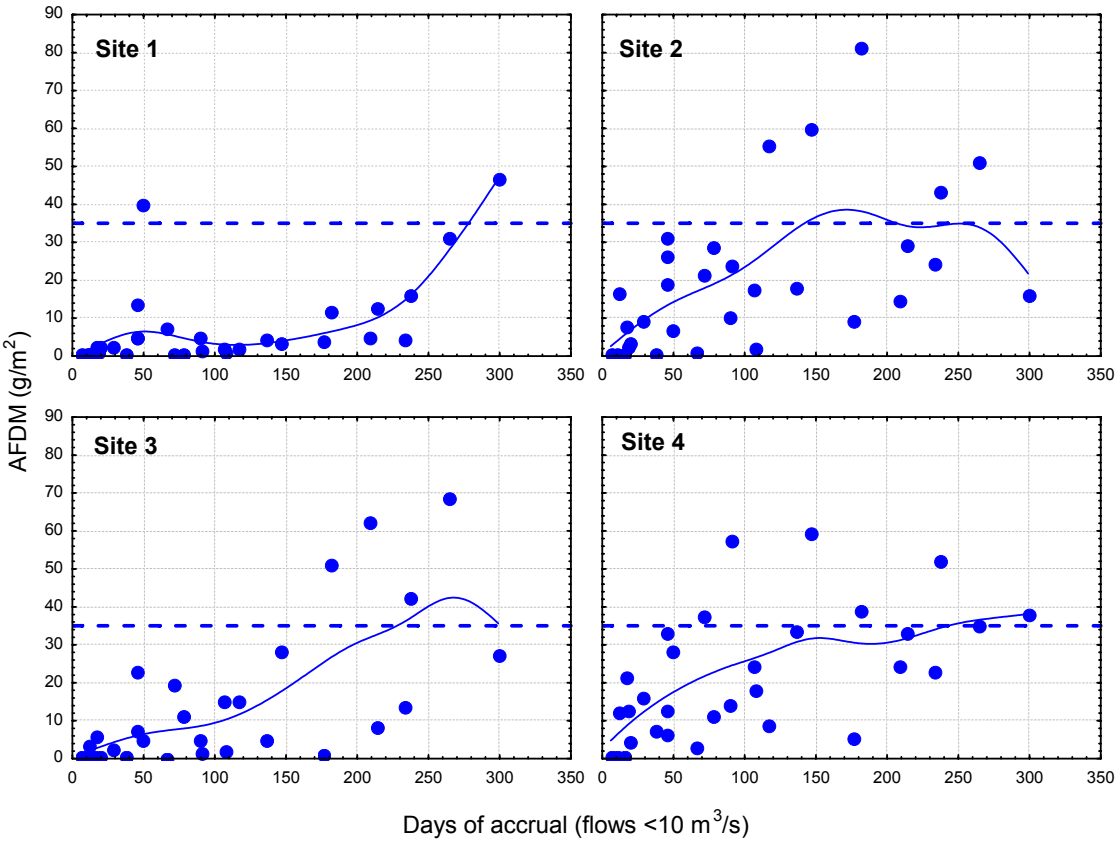

Figure 6.2 **Relationship between days of accrual and AFDM measurements. The line of best fit was determined using distance weighted least squares regression (Statsoft, 2002). The dashed line is the periphyton guideline value (MfE, 2000).**

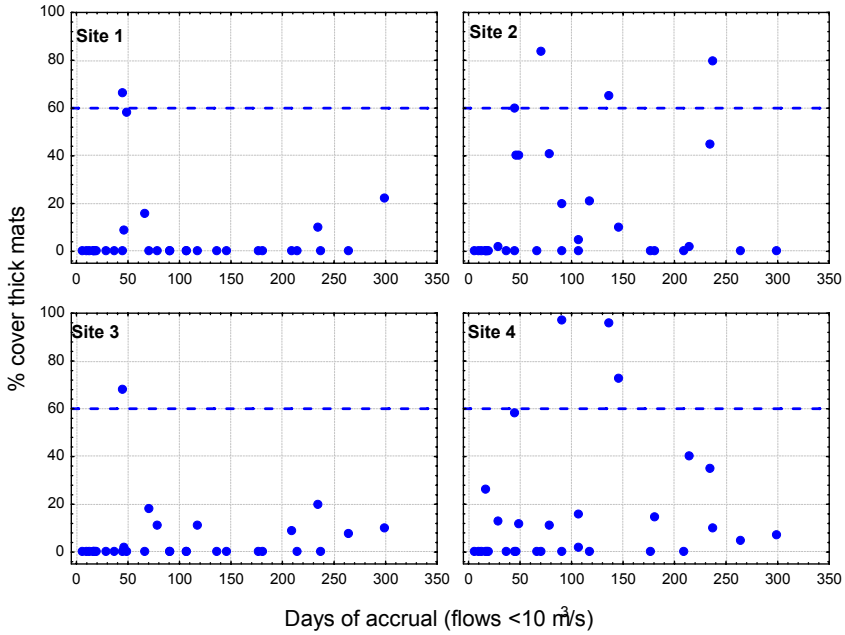

Figure 6.3 **Relationship between percent cover of thick periphyton mats with days of accrual. Dashed line is the periphyton guideline (MfE, 2000).**

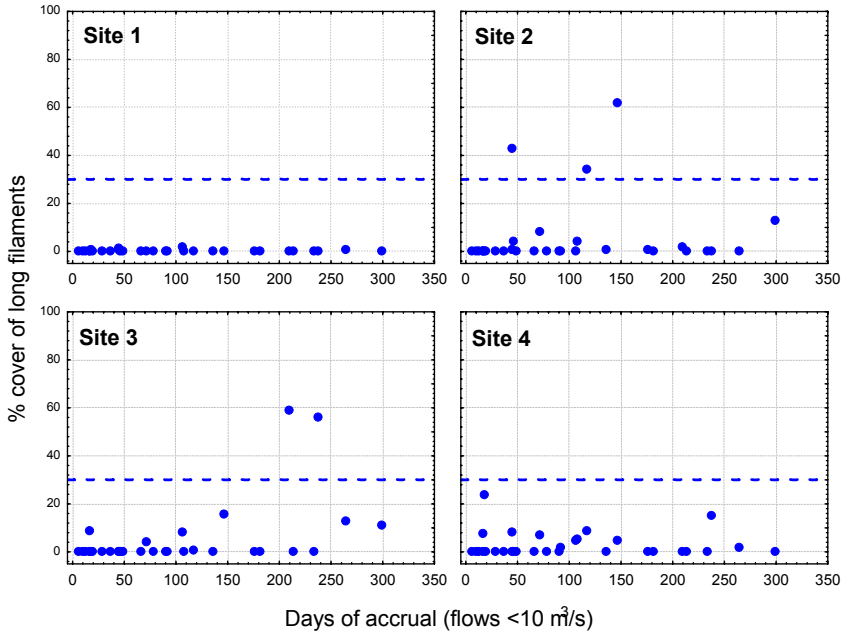

Figure 6.4 **Relationship between percent cover of long filamentous periphyton growths with days of accrual. Dashed line is the periphyton guideline (MfE, 2000).**

6.2.3 Annual variations in biomass as a function of flow regimes

Examination of the hydrological data over the monitoring period showed there were two distinctly different years in terms of frequency of floods and extent of low stable flows (Figure 6.5). Comparison of these different flow regimes was undertaken to determine medium term patterns (yearly) in periphyton development as a function of flows. For this purpose data from two consecutive years were compared. The first period was from October 1999 to September 2000, and the second year period from October 2000 to September 2001. These time periods were chosen because of the major flood in August 2000 followed by prolonged high flows into September, which allowed a clear separation of accrual periods, and because after this flood new reaches of the river were used for three of the sites (see Methods section). Therefore, this also allowed reach habitat variables to be consistent at each site, within each time period.

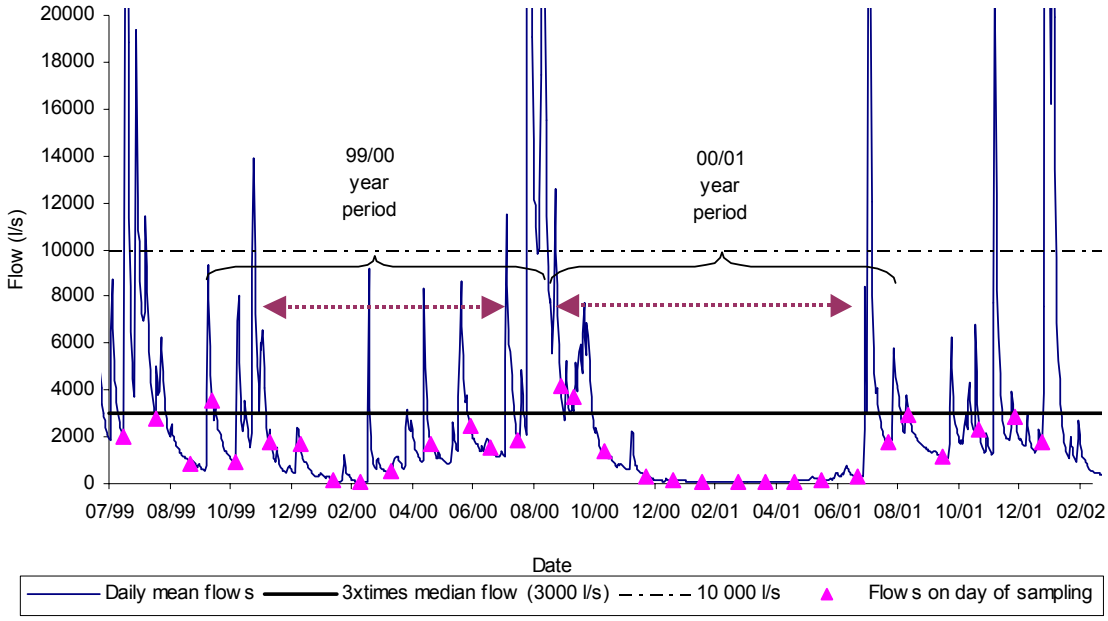

Figure 6.5 Hydrograph of mean daily flows at Environment Canterbury's flow recorder site at White Gorge, Waipara River. Dashed arrows show the main accrual periods for each year.

Table 6.2 summarises the hydrological data for each time period, calculated from mean daily flow data from Environment Canterbury's flow recorder at White Gorge. The mean and median flows were higher during 99/00 compared to 00/01. The maximum accrual period (number of consecutive days between flood events of magnitude greater than 10 m^3/s) during 99/00 was 249 days and 309 days during 00/01. The median flow for these periods was 1072 and 176 l/s respectively. There were twice as many floods (>10 m^3/s) during 99/00 than 00/01, similarly FRE_3 was nearly twice as high in 99/00. Therefore, not only did the 00/01 year have a longer period of stable flow, but also the flows were also considerably reduced during this period.

Table 6.2 Summary of flow data from flow recorder located at White Gorge for the two years of monitoring

	Oct 99 - Sept 00	Oct 00 - Sept 01
Mean flow (l/s)	4087	1355
Median flow (l/s)	1441	264
Mean days of accrual (FRE_3)	33	98
FRE_3 (no. floods > 3xmedian flow)	9	5
Mean days of accrual (periods <10 000 l/s)	77	178
Max. days of accrual (periods <10 000 l/s)	249	309
No. flood events > 10 000 l/s	4	2
Lowest mean daily flow (l/s)	69	47
Median flow during longest accrual period (l/s)	1072	176

Statistical analysis (Student's T test) of differences in chl. *a* and AFDM values the two years was performed on the log transformed data for each site. There were no significant differences (p >0.05) between the years for any of the sites. However, despite this, the average biomass measurements were higher for each site during the 00/01 year than in the 99/00 year (Table 6.3). The maximum biomass at all sites was considerably higher in the 00/01 year than the 99/00 year, with biomass values transgressing guideline values during the 00/01 year at all sites. This compares with only one sample at Site 4 transgressing guideline values in the 99/00 year.

The total percent cover of periphyton at each site was greater during the 00/01 year than during 99/00 (Table 6.4). This is consistent with higher chl. *a* and AFDM values during 00/01. At Site 1, the average percent cover of medium thick and thick mats was twice as high in 00/01 than 99/00. The other periphyton groups were similar in both years at this site, including negligible growth of filamentous algae. At Site 2, the average percent cover of all mat growths

was less during 00/01 than for the previous period, while the average percent cover of filamentous algae was higher in the second year. The percent cover of mats at sites 3 and 4 was generally similar or less in the 00/01 year than the previous year, while the average percent cover of filamentous algae was considerably higher in the 00/01 year.

Table 6.3 Comparison of periphyton biomass data for each site for two different years of contrasting flow regimes.

		Site 1		Site 2		Site 3		Site 4	
		99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01
Periphyton									
Chlorophyll a	**average**	**10.2**	**17.2**	**48.9**	**150.0**	**13.8**	**117.5**	**77.9**	**135.0**
	median	4.5	9.0	31.0	112.0	8.0	66.5	61.0	112.5
	max.	47.0	54.0	194.0	325.0	54.0	455.0	292.0	331.0
No. of samples above GV		*0*	*0*	*0*	*4*	*0*	*3*	*1*	*4*
ADFW	**average**	**4.0**	**13.5**	**15.2**	**29.7**	**6.4**	**25.3**	**15.6**	**29.5**
	median	4.1	4.3	16.9	20.0	5.5	21.3	13.1	31.6
	max.	12.5	46.9	29.1	81.3	15.1	68.8	33.5	59.3
No. of samples above GV		*0*	*2*	*0*	*5*	*0*	*4*	*0*	*5*
Taxonomic richnes	average	44	37	40	38	34	35	37	35
	median	37	39	40	38	35	36	38	34
Water quality									
Conductivity	**average**	**18**	**28**	**23**	**36**	**24**	**35**	**31**	**41**
	median	16	30	20	39	23	38	30	45
	max.	25	40	35	51	34	44	38	48

GV = periphyton guideline value (200 mg/m^2 for chl. *a*, 35 g/m^2 for AFDM)

Table 6.4 Comparison of average percent cover of different periphyton groups at each site between the different years. Shaded cells indicate recreational/aesthetic guidelines exceeded.

Periphyton groups		**Site 1**		**Site 2**		**Site 3**		**Site 3**	
		99/00	**00/01**	**99/00**	**00/01**	**99/00**	**00/01**	**99/00**	**00/01**
Thin film	**average**	**20**	**20**	**11**	**8**	**22**	**12**	**9**	**14**
	maximum	46	54	35	45	80	50	44	66
Medium thick mats	**average**	**15**	**30**	**26**	**19**	**22**	**12**	**33**	**24**
	maximum	47	100	75	72	70	31	97	63
Thick mats	**average**	**3**	**7**	**17**	**14**	**3**	**3**	**19**	**18**
(GV = 60%)	maximum	16	58	65	80	20	11	96	97
Filaments - short	**average**	**0**	**1**	**12**	**27**	**1**	**17**	**3**	**23**
	maximum	2	6	58	88	7	52	16	87
Filaments - long	**average**	**0**	**0**	**1**	**9**	**1**	**13**	**1**	**3**
(GV = 30%)	maximum	2	1	4	62	9	59	8	15
Total cover		***37***	***57***	***66***	***77***	***48***	***57***	***64***	***82***

Relative abundance data of taxa in periphyton samples also showed differences between years and among the sites. In particular, the average relative abundance of *Cladophora glomerata* showed a marked increase at the three downstream sites from the 99/00 year to the 00/01 year. This is consistent with the percent cover data showing much higher cover of filamentous algae in the 00/01 year. *Cladophora glomerata* was very rarely observed in samples from Site 1. The diatoms *Cocconies pediculus* and *Synedra ulna* var. *biceps* also showed a pattern of generally higher average relative abundance scores during 00/01 than in the previous year. In contrast, the relative abundance of the diatom *Gomphoneis minuta* var. *cassieae* and *Epithemia sorex* was generally lower during 00/01 than the previous year.

Table 6.5 Comparison of average relative abundance scores for the main algal species at each site between the different years.

	Site 1		Site 2		Site 3		Site 4	
Taxa	**99/00**	**00/01**	**99/00**	**00/01**	**99/00**	**00/01**	**99/00**	**00/01**
Bacillariophyta								
Cocconeis pediculus	1	2	4	5	3	4	5	4
Cocconeis placentula	4	3	3	2	2	2	3	2
Cymbella kappii	3	4	4	4	3	4	4	4
Cymbella tumida	1	3	2	2	1	2	1	1
Encyonema minutum	2	1	3	2	2	1	4	2
Epithemia sorex	4	3	5	1	5	2	3	2
Gomphoneis minuta var cassieae	5	3	6	4	4	2	5	5
Melosira varians	4	3	4	3	2	2	4	4
Navicula lanceolata	1	2	2	2	1	2	2	3
Nitzschia c.f. palea	3	3	2	3	2	3	3	3
Rhopalodia novae-zealandiae	0	2	0	0	0	0	0	0
Synedra acus	2	2	3	2	2	2	2	2
Synedra ulna var biceps	1	1	3	4	2	4	3	4
Synedra ulna var contracta	2	1	2	2	2	1	1	3
Synedra ulna var ramesi	2	0	3	1	3	1	3	2
Synedra ulna var.1	2	3	2	2	2	1	3	1
Chlorophyta - filamentous								
Cladophora glomerata	0	0	1	4	0	3	2	4
Mougeotia sp.2	1	2	1	1	2	0	1	0
Ulothrix zonata	1	1	2	2	0	0	1	2
Zygnema sp.1	0	0	0	0	0	2		

6.2.4 Periphyton development during long accrual periods

From the above results, the different flow regimes resulted in differences between the annual average and maximum biomass and composition of periphyton communities. While both years examined had a long period of accrual, the duration and extent of low flows during the main accrual periods differed. The development of periphyton during the long stable flow periods for each of the years was examined in more detail.

Figures 6.6 to 6.9 show the relative abundance of the major species and percent cover of periphyton growth forms during the two main periods of accrual during the study. An accrual period of 249 days occurred during the 99/00 year (21/11/99 to 27/7/00). In the 00/01 year, 309 continuous days of accrual occurred (7/9/00 to 20/7/01). While the mean daily flows for both periods were less than 10 m^3/s, the 99/00 period had several small spates. These spates were probably of sufficient magnitude to result in some periphyton loss. The median flow during the 99/00 accrual period was 1072 l/s (Table 6.2). In contrast, there was only one spate at the beginning of the 00/01 accrual period, followed by a recession in flows until April 2001, when flows started to gradually increase. The median flow for this period was 176 l/s. Included are surface velocity data collected during the monitoring programme (see methods section). While this data does not accurately reflect mean water column velocities, it does give an indication of the relative differences in water velocities at each site and over time.

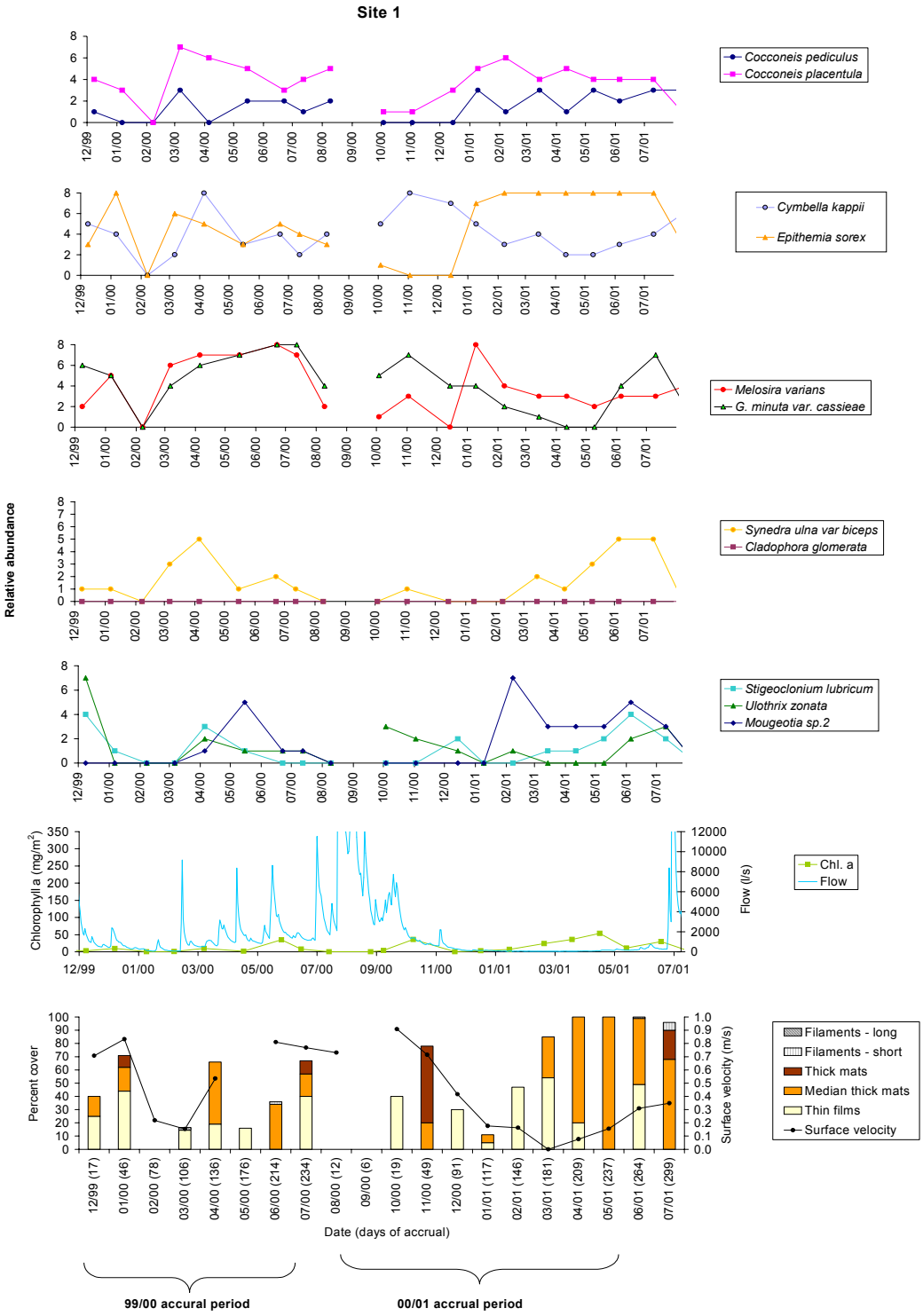

Figure 6.6 **Development of biomass (chlorophyll *a*), percent cover of main growth forms and relative abundance of main algal species during the two prolonged periods of accrual at Site 1.**

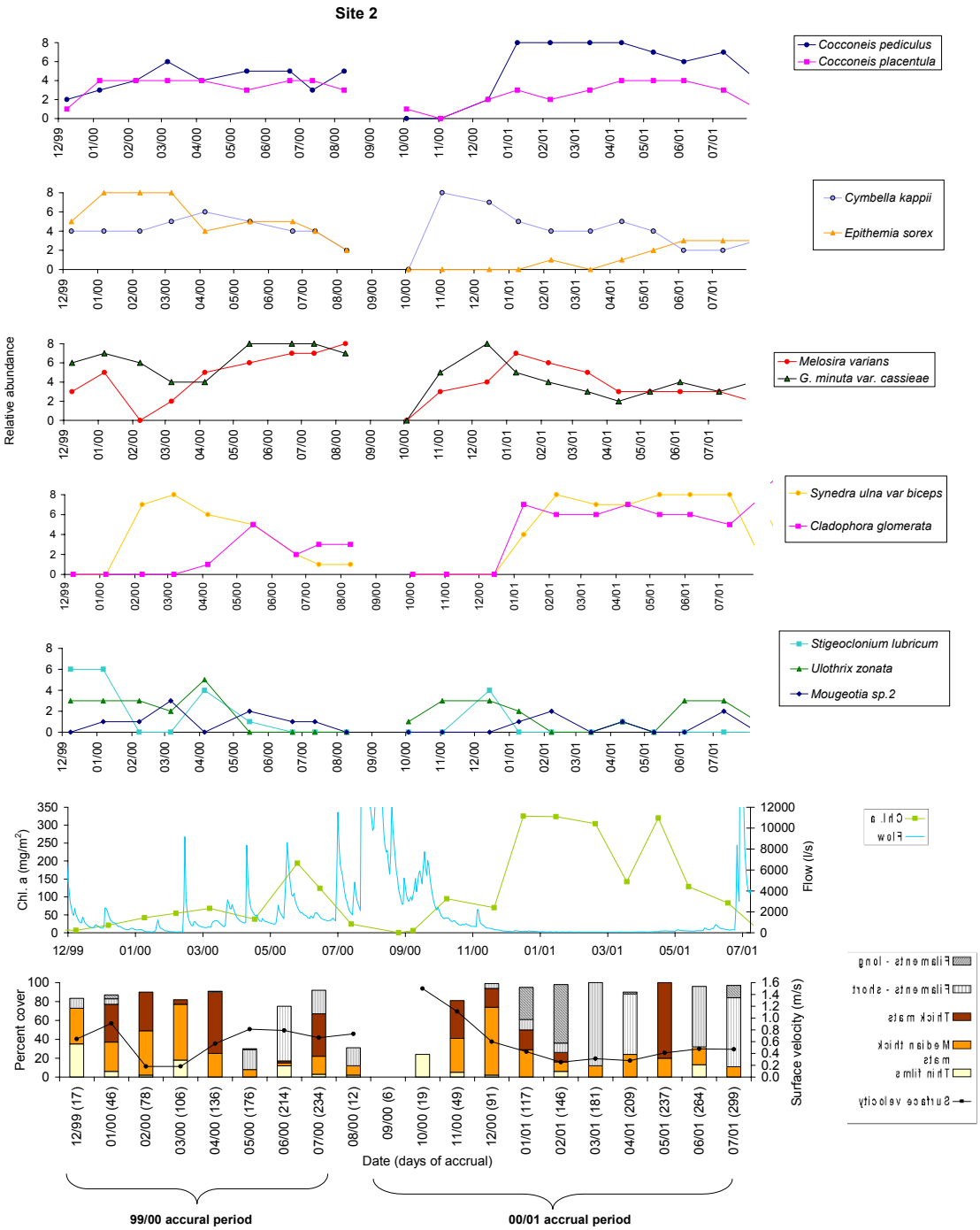

Figure 6.7 **Development of biomass (chlorophyll *a*), percent cover of main growth forms and relative abundance of main algal species during the two prolonged periods of accrual at Site 2.**

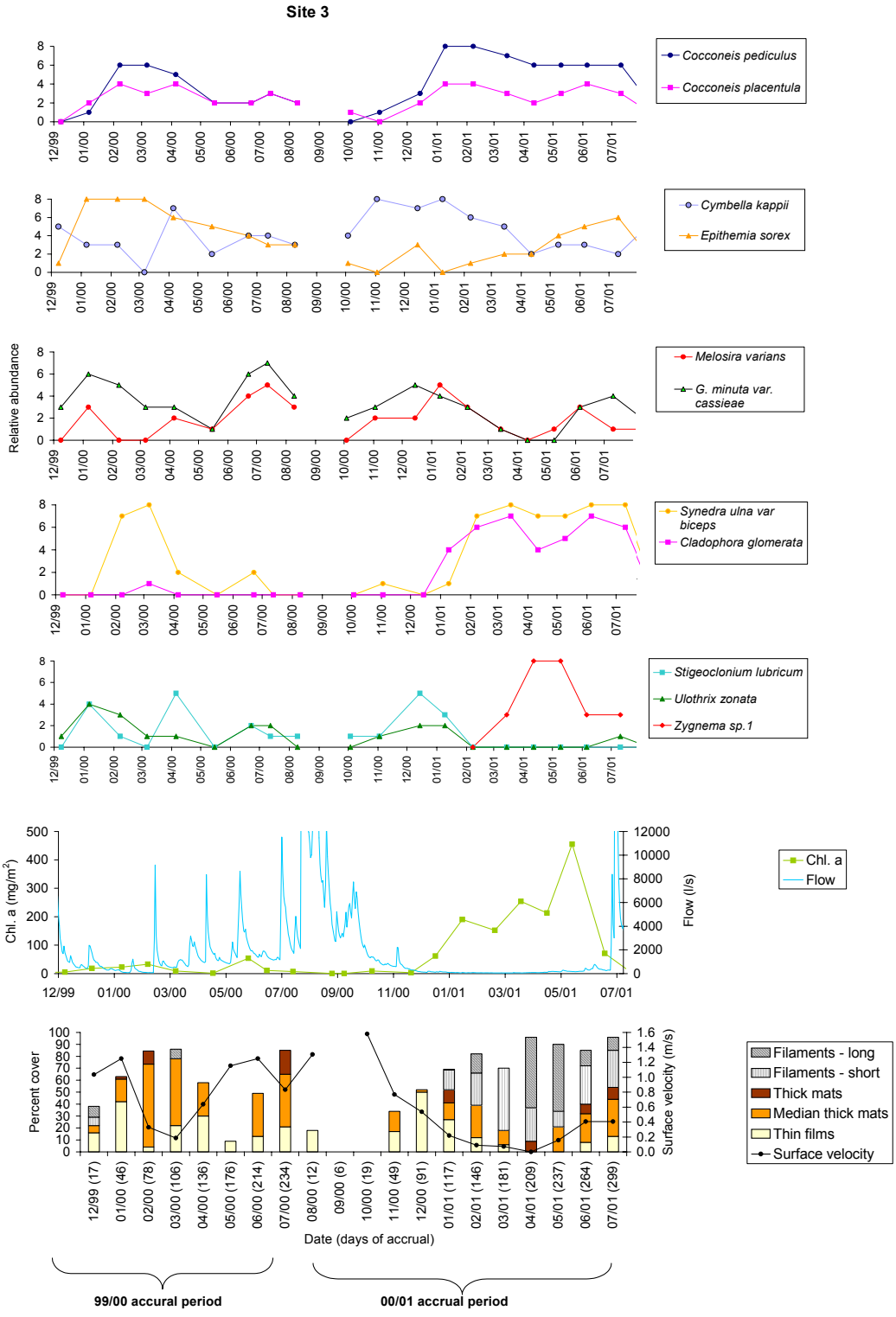

Figure 6.8 **Development of biomass (chlorophyll *a*), percent cover of main growth forms and relative abundance of main algal species during the two prolonged periods of accrual at Site 3.**

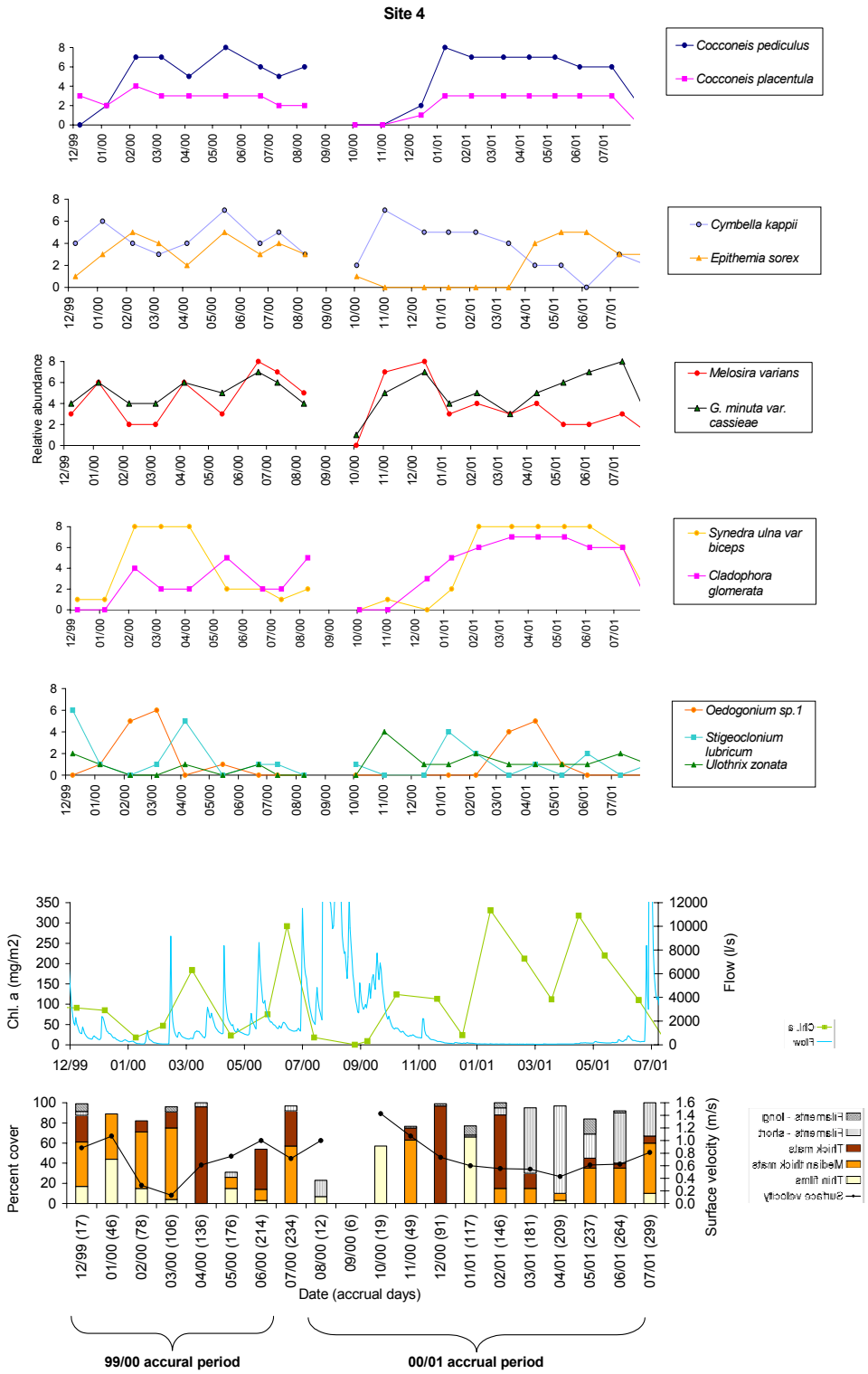

Figure 6.9 **Development of biomass (chlorophyll *a*), percent cover of main growth forms and relative abundance of main algal species during the two prolonged periods of accrual at Site 4.**

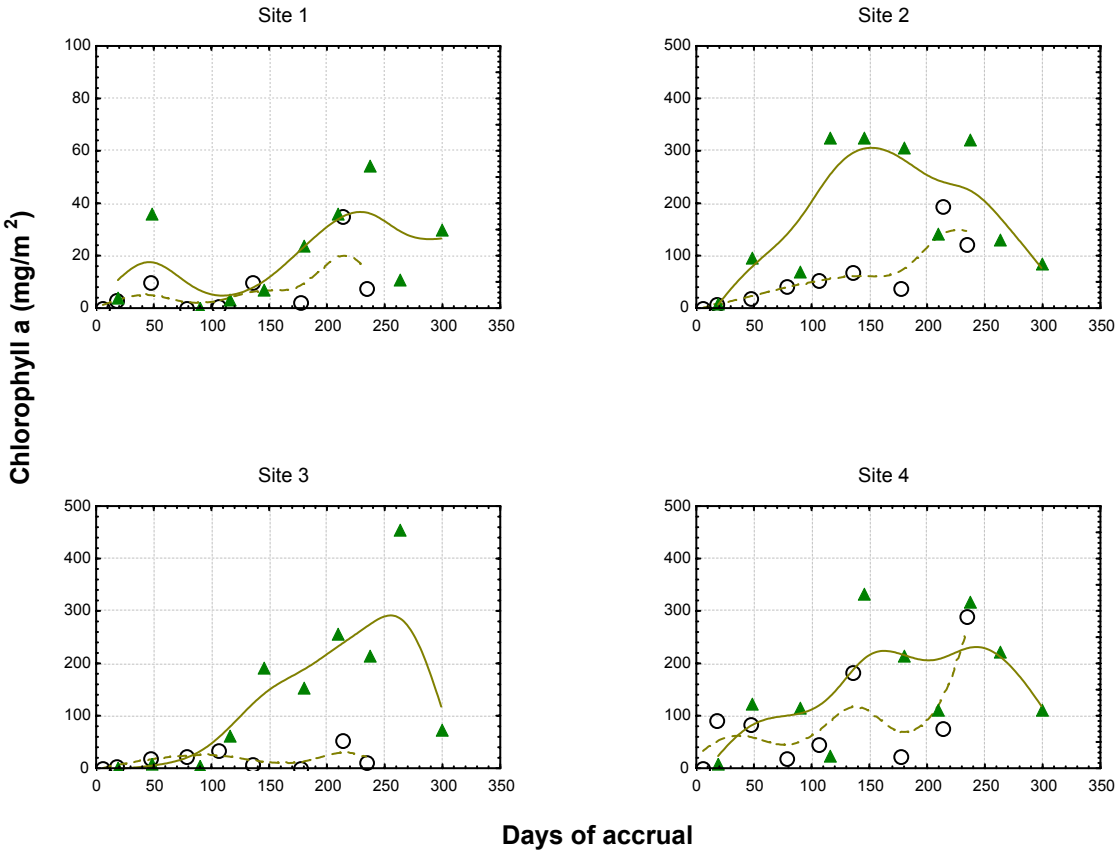

Figure 6.10 **Chlorophyll *a* values during the two main accrual periods as a function of days of accrual. Open circles and dashed lines represent samples collected during December 1999 to July 2000, closed triangle and solid lines represent samples collected during October 2000 to July 2001. Note the different scale for chl. *a* at Site 1. The lines of best fit were determined using distance weighted least squares regression**

Periphyton development responded differently at each site to the variations in flow during the main accrual periods. At Site 1, the overall biomass remained low and very little filamentous algae developed as discussed in previous sections (Figure 6.6). This is despite low surface water velocities occurring during the 00/01 period. The rate of biomass accrual and magnitude of peak biomass were similar for both periods. The timing of peaks in biomass were also similar in terms of days of accruals (Figure 6.10). *Ulothrix zonata* was abundant at this site during the early summer sample in December 1999 and *Mougeotia* sp. 2 was common to abundant during late summer and autumn of both periods but otherwise, the filamentous green taxa occurred in low abundance. *Melosira varians* and *Gomphoneis minuta* var. *cassieae* were the dominant diatoms found at this site during the high flow accrual period. During the low flow accrual period, these diatoms were initially present as dominant or abundant, but their relative abundance generally decreased with increasing accrual period. *G. minuta* var. *cassieae* did increase in abundance towards the end of the accrual periods as water velocities were starting to increase. In contrast, *Epithemia sorex* rapidly became the dominant diatom species during the low flow accrual period and persisted as dominant species throughout this period. It was less abundant during the high flow accrual period. The percent cover during the low flow accrual period showed generally low to moderate amounts of thin and medium thick mats, but only minor amounts of the other periphyton forms. This changed slightly during the low flow accrual period, with generally higher percent cover of medium thick mats developing after about 200 days of accrual at low flows.

During the high flow accrual period, surface velocities at Site 1 were lowest during February and March (0.22 and 0.15 m/s respectively). However, surprisingly during these two months the percent cover and chl. *a* values were lowest for this accrual period. During the low flow accrual period, the periphyton biomass generally increased with decreasing flows and increasing accrual periods. The one exception to this was the sample collected in November 2000, which had a moderate chl. *a* value (36 mg/m^2), high AFDM value (39.9 g/m^2, see Section 4) and a high percent cover of thick mats. This was despite a moderately high surface velocity of 0.71 m/s.

There were many similarities in the development of periphyton during the low flow accrual periods between sites 2, 3 and 4 (Figures 6.7, 6.8 and 6.9). During the high flow accrual period, biomass remained low at Site 3, but some high chl. *a* values occurred at Sites 2 and 4. Medium thick mats and thick mats were the dominant form of periphyton at these three sites during the high flow accrual period. However, during the low flow periods, the percent cover

of filamentous algae (short and long filaments) increased markedly during the accrual period. Maximum cover of filamentous growth occurred during the period of lowest surface velocities at all three sites. The percent cover of filamentous algae generally declined towards the end of this accrual period as water velocities gradually increased. Correspondingly, the relative abundance of the filamentous green alga *Cladophora glomerata* rapidly increased in abundance to become dominant or abundant at these three sites during the low flow accrual period. The epiphytic diatoms *Cocconeis pediculus* and *Synedra ulna* var. *biceps* increased in relative abundance in conjunction with increases in abundance of *C. glomerata*. During taxonomic analyses of the samples, these diatoms were commonly observed as epiphytes on the *C. glomerata* filaments. At Site 3, the filamentous alga *Zygnema* sp. 1 developed a high relative abundance during April and May 2000, when surface velocities were lowest. *Zygnema* sp. 1 was observed as conspicuous green floating growths at the edge of the stream and was the main component of the long green filamentous growth recorded at this site. This species was not found in any notable abundance at the other three sites. As with Site 1, the relative abundances of *M. varians* and *G. minuta* var. *cassieae* showed strong correlations with changes in surface velocities, in that they were highest during high flows and decreased with decreasing flows.

The rate of biomass accrual was higher at Site 2 during the low flow accrual period than the high flow period. Time to peak biomass also considerably shorter (~117 days) during the low flow period than the high flow period (214 days) (Figure 6.10). At Site 3, the biomass remained low during both accrual periods for up to 100 days after which a rapid rate of accrual occurred during the low flow period while biomass remained low during the high flow period. Similar rates of accrual and timing of biomass peaks were found at Site 4 during both accrual periods. While the biomass was generally higher at this site during the low flow accrual period, cycles of accrual and sloughing appeared to occur after similar time periods. A peak in biomass occurred after approximately 140 days of accrual during both periods followed by a decrease in biomass and another peak occurring after about 230 days of accrual. In the latter case, the biomass was very similar.

6.3 Discussion

Defining flow-related disturbance events is difficult given that periphyton response to disturbance depends on many factors including community composition, pre-flood conditions, age and physiology of the community. Hydrological variables such as water velocity, changes in flows compared to base flows and magnitudes of floods have been used to define disturbance events (e.g. Biggs & Close, 1989; Biggs, 1995). Examination of changes in biomass following floods of various magnitudes in the Waipara River indicated that floods with flows above 10 m^3/s generally resulted in major destruction of periphyton communities. Smaller floods had varying effects on periphyton biomass. Certainly, some floods of between 4 to 10 m^3/s resulted in biomass loss but not all. The percent change in biomass as a function of peak flood events showed some sampling occasions with surprisingly large increases in biomass despite floods of between 4 m^3/s to 9 m^3/s In some instances, this may have been the result of rapid re-colonisation and re-growth, indicating strong community resilience, rather than community resistance to disturbance (Biggs *et al.*, 1999b).

Biomass values as a function of days of accrual were highly variable but did show a general pattern of the greatest biomass occurring after prolonged accrual periods. Biomass and percent cover values generally exceeded aesthetic/recreational guideline values only after about 100 days accrual. The rate of accrual appeared highest at Site 4, the most nutrient rich site, and generally lowest at Site 1, the most nutrient impoverished site.

Medium term (yearly) patterns in biomass as a function of different flow regimes showed a general pattern of higher biomass occurring during the period of more stable flows. While the differences in chl. *a* and AFDM were not statistically significant between the periods at any of the sites, the consistently higher average and maximum values at all sites during the stable flow period indicated that overall periphyton production was higher in the second year. This suggests the flow regime has a controlling effect on biomass development.

Hydrological variations in flows between the two periods consisted of a lower frequency of major floods (>10 m^3/s) and spates (>3 m^3/s) as well as considerably reduced flows in the 00/01 year (Table 6.2). The median flow during the 00/01 main accrual period was more than 10 times lower than that during the 99/00 accrual period. This raises the question of whether the frequency of flood events or the extent of low flows was the controller of periphyton biomass. It is likely that both of these hydrological factors were important, but to different degrees at each site. The reach at Site 3 appeared relatively unstable, with frequent changes to

the channel position as a result of minor floods. It is likely that the frequency of even minor spates and consequent bed movement was a major controlling factor of biomass at this site (Biggs *et al.,* 1999a). Only during the period of very stable flows did periphyton biomass at this site proliferate. The development of filamentous algae occurred at this site only when water velocities were very low, and cover decreased as water velocities started to increase.

In contrast, while the spates occurring during the high flow period would have resulted in some biomass loss at Site 4, the rate of biomass accrual appears sufficiently rapid that a prolific biomass was able to develop during both accrual periods. However, the development of filamentous algae only occurred during the period of low water velocities, although long filamentous growth forms did not generally develop at this site. The surface velocities were highest at this site, as well as flows being higher than the upstream sites because of the inflow of the Omihi Stream, which contributes to about 25% of the flows at Site 4 during low flows (Chater, 2002). It is likely that the higher water velocities at this site, and therefore higher shear stress, limit the abundance of long filamentous algal growths.

Site 1 was probably least affected by differences in flows between the years and by the extent of low flows during 2001. Biomass at this site remained generally low throughout the survey. Other factors appear to be the major controllers of periphyton development at this site. In particular, moderately low nutrient concentrations (see Chapter 5) appear to be the main controlling factor, so that variations in flows have much less of an impact at this site than at the more enriched downstream sites. This is similar to the findings of Suren *et al.* (2003a), when they compared biomass production at a site on the lower Waipara River to that in the neighbouring unenriched Okuku River. Their findings suggested that nutrient availability was the limiting controller on biomass development in the Okuku River, rather than flow regimes. In contrast, the high biomass they found in the lower Waipara River was the result of nutrient enrichment, which was expressed as very high algal biomass during the low flow period.

The development of prolific growths of long filamentous algae occurred primarily at sites 2 and 3, and only during the low flow accrual period. The maximum cover of filamentous algae at both sites occurred at the time of lowest surface velocities and lowest flows. As with Site 4, the percent cover of filamentous growths decreased as flows gradually increased during the latter stage of the accrual period. These results suggest that low water velocities are an important factor in the development of filamentous algae. However, this is only possible when

the limitations of laminar boundary effects at low water velocities are overcome by highly nutrient-enriched waters.

7 Invertebrates

7.1 Introduction

Freshwater aquatic invertebrates play an integral part in stream ecosystems. They are both the grazers of photosynthetic products (algae – autochothonous material) and other micro-organisms, as well as consumers of organic and inorganic detrital material from terrestrial sources (allochothonous). Some species are predators, and higher organisms (fish and birds) rely on many species of invertebrates as a main food source.

The interaction of invertebrates and periphyton is complex. Many invertebrate species are obligatory or facultative grazers of periphyton (function feeding group – collectors/browsers, also commonly called grazers (Winterbourn, 2000)). New Zealand stream invertebrates are generally considered non-specialist feeders and are able to consume a variety of food types. In addition to being a food source, the presence of periphyton modifies the stream habitat by covering the substrate, altering stream chemistry (e.g. pH, dissolved oxygen concentrations) and near-bed velocities, and impeding visibility. These changes in stream habitat can result in changes to the types of invertebrates present.

On a habitat template of Biggs *et al*, (1998) invertebrate grazing is the third axis of factors controlling periphyton development. The negative effects of grazers on periphyton biomass has been well studied (Steimnan, 1996). Several studies in New Zealand streams have demostrated effects of grazing invertebrates on periphyton biomass (e.g. Winterbourn & Fegley, 1989; Winterbourn, 1990; Biggs & Lowe, 1994). In these studies, periphyton biomass was generally considerably higher on substrates where invertebrates were excluded, than on substrates including invertebrate populations.

Macro-invertebrates have been commonly used in New Zealand and overseas as indicators of stream health (Stark, 1993; Quinn *et al.,* 1997; Winterbourn, 1981; Boothroyd & Stark, 2000). The Macro-invertebrate Community Index (MCI) and its derivatives (semi-quantitative MCI, quantitative MCI) has been developed for the main aquatic invertebrate taxa in New Zealand streams (Stark, 1985, 1998). This index is based on the tolerances of the invertebrates to organic enrichment of streams. However, as it is based on the distribution of taxa for a range of river types grouped according to the degree of human impact, the index therefore responds

to a complex range of environmental factors including, but not confined to, water quality (Boothroyd & Stark, 2000).

The SHMAK invertebrate monitoring method, as used in this study, is a simple field assessment of invertebrate groups present on individual stones examined (see Methods section for details). Recommended procedures for assessing indicator stream invertebrates involve more rigorous sample collection techniques such as surber sampling or kicknet (Stark *et al,* 2001). The method employed in this study may result in the under representation of some mobile species such a mayflies and overrepresentation of immobile species such as chironomids. However, while the data collected in this study can neither be directly compared to that collected by more rigorous methods, nor be used to calculate indices such as MCI, it still provides a valuable and rapid method of comparing differences in invertebrates between sites and as function of periphyton development over time. Table 7.1 shows the invertebrate groups and pollution tolerant scores as given by Biggs *et al.,* (1998b). The pollution tolerant scores are based on the MCI index.

The aim of this part of the study was to examine the interaction of periphyton and invertebrate communities at the four sites on the Waipara River. Detailed taxonomic identification was not routinely undertaken, although some samples were examined with Environment Canterbury officers trained in invertebrate identification in order to gain confidence in field identifications.

7.2 Results

The highest total densities of individuals were generally found at sites 2 and 4 (Figure 7.1). Site 4 had the greatest maximum density of invertebrates. Sites 1 and 3 had similarly lower ranges of invertebrate densities. Of the main groups of invertebrates, caddisfly larvae (several types) were by far the most abundant group found at all sites (Figure 7.2). Taxonomic examination of samples showed *Aoeteapsyche* and *Pycnocentrodes* were the most commonly occurring caddisflies this group. The overall density and relative abundance of this group were generally highest at Site 1. The density and relative abundance of the more pollution tolerant 'axehead' caddisfly (mostly *Oxythira*) was generally higher at sites 2 and 4 (Figure 7.2). Similarly, the density and relative abundance of pollution tolerant midges and snails were higher at sites 2 and 4 (Figure 7.3). In contrast, while the pollution sensitive mayflies occurred in greatest density at Site 2, their relative abundance was generally highest at Site 1 (Figure 7.2). *Deleatidium* was the only mayfly found in the samples examined for taxonomic

identification. Ostracods, while generally in low abundance at all sites, were occasional present in very high numbers at sites 3 and 4.

Table 7.1 List of invertebrate groups, common species and pollution tolerant score of the grouping used in the SHMAK field assessment (modified from Boothroyd & Stark, 2000).

Type of invertebrates	Scientific name	Taxon score	Types of invertebrates found at Waipara River sites
Worms	Oligochaetes, mainly *Tubifex*	1	✓
Ostracods	Ostracoda	1	✓
Midge larvae	Chironomidae	2	✓
Flatworms, leeches	Platyhelminthes, Hirudinea	3	✓
Snails, rounded	*Physa* and others	3	✓
Small bivalves	*Psidium* etc.	3	✖
Axehead caddis larvae	*Oxythyra albiceps, Paroxyethira* sp.	3	✓
Snails, pointed end	*Potamopyrgus*	4	✓
Amphipods and water fleas	Amphipoda and Cladocera	5	✖
Cranefly larvae	e.g. *Aphrophila*	5	✖
Beetle larvae and adults	e.g. Elmidea	6	✓
Caddisfly larve (several types)	e.g. *Pycnocentrodes, Aeotapsyches, Hydrobiosis*	6	✓
Limpet-like molluscs	*Latia* sp.	7	✖
Smooth-cased caddisflies	*Olinga feredayi*	9	✓
Mayflies	Ephemeroptera (e.g. *Deleatidium*)	9	✓
Spiral-cased caddisfly	*Helicopsyche* sp.	10	✖
Stoneflies	Plecoptera (e.g. *Stenoperla, Megaleptoperla*)	10	✖

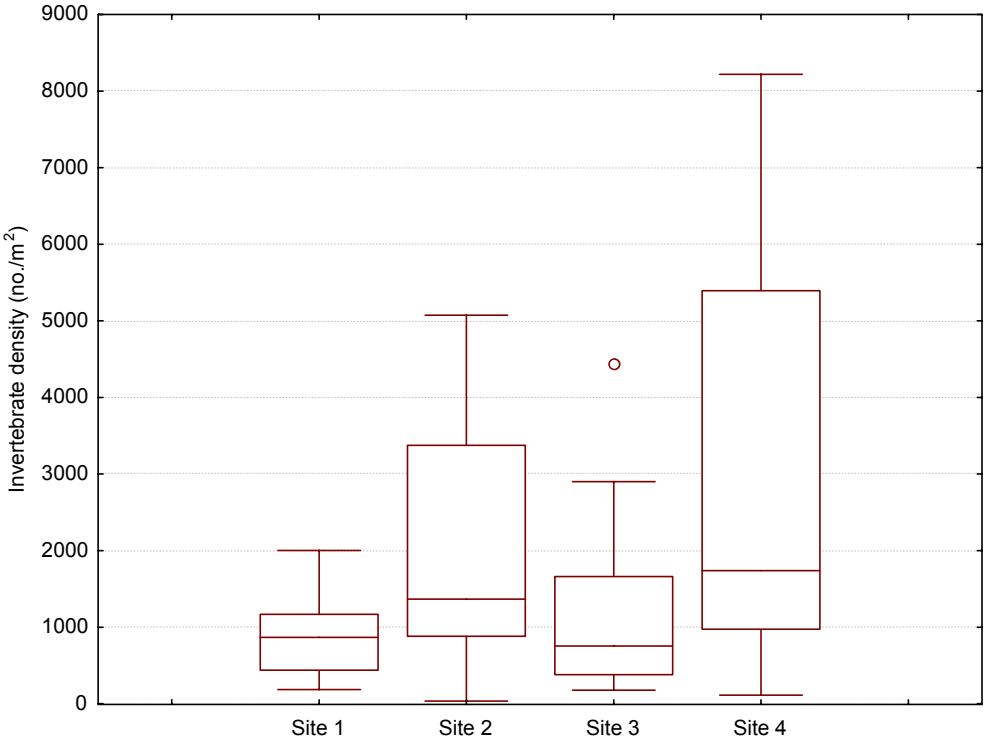

Figure 7.1 Total invertebrate density from field assessments at four sites on the Waipara River.

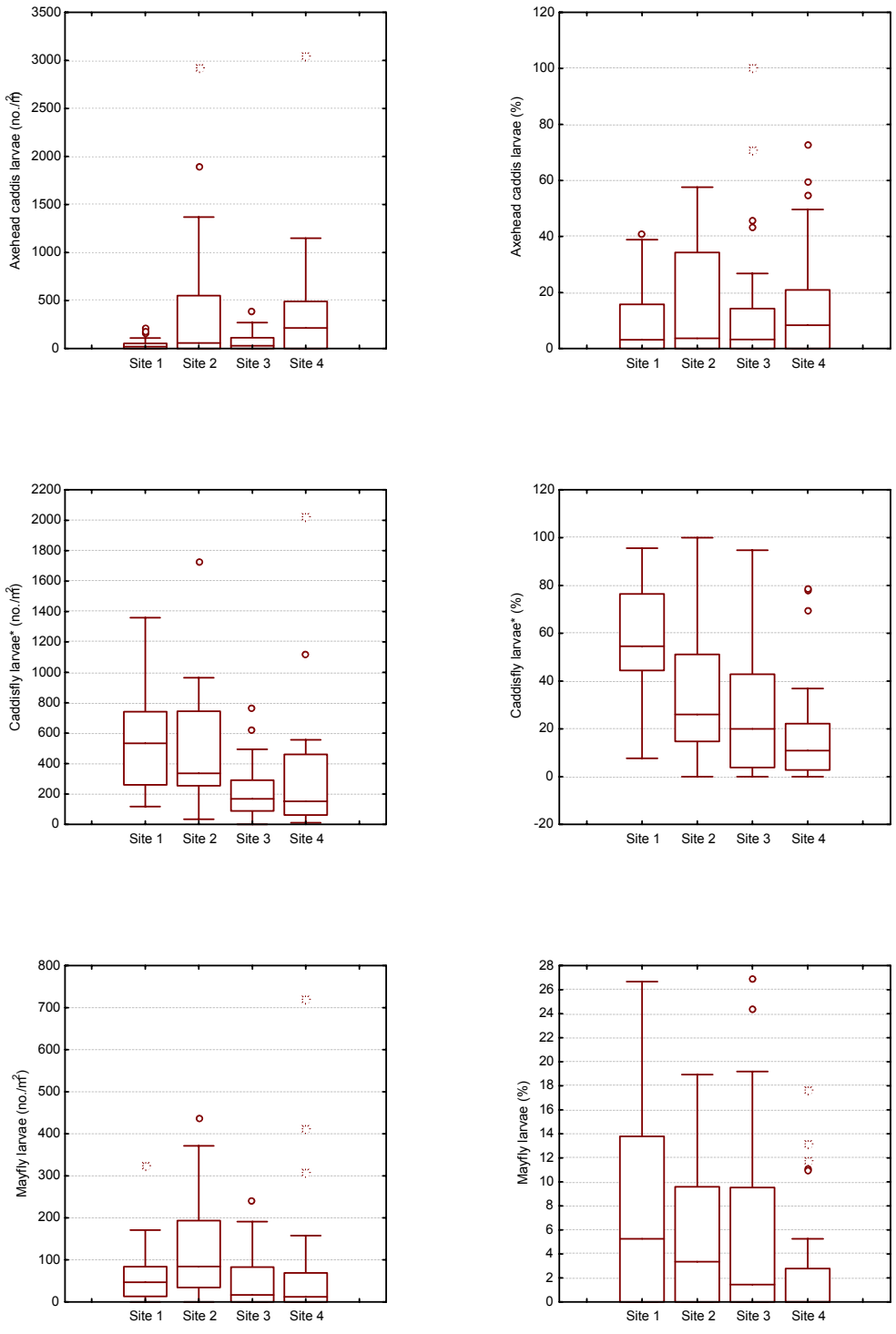

Figure 7.2 **Density and relative abundance (%) of the invertebrate groups found at the four sites on the Waipara River. *These are the group of caddisfly larvae of 'mixed types' in Biggs *et al.* (1998) identification guide.**

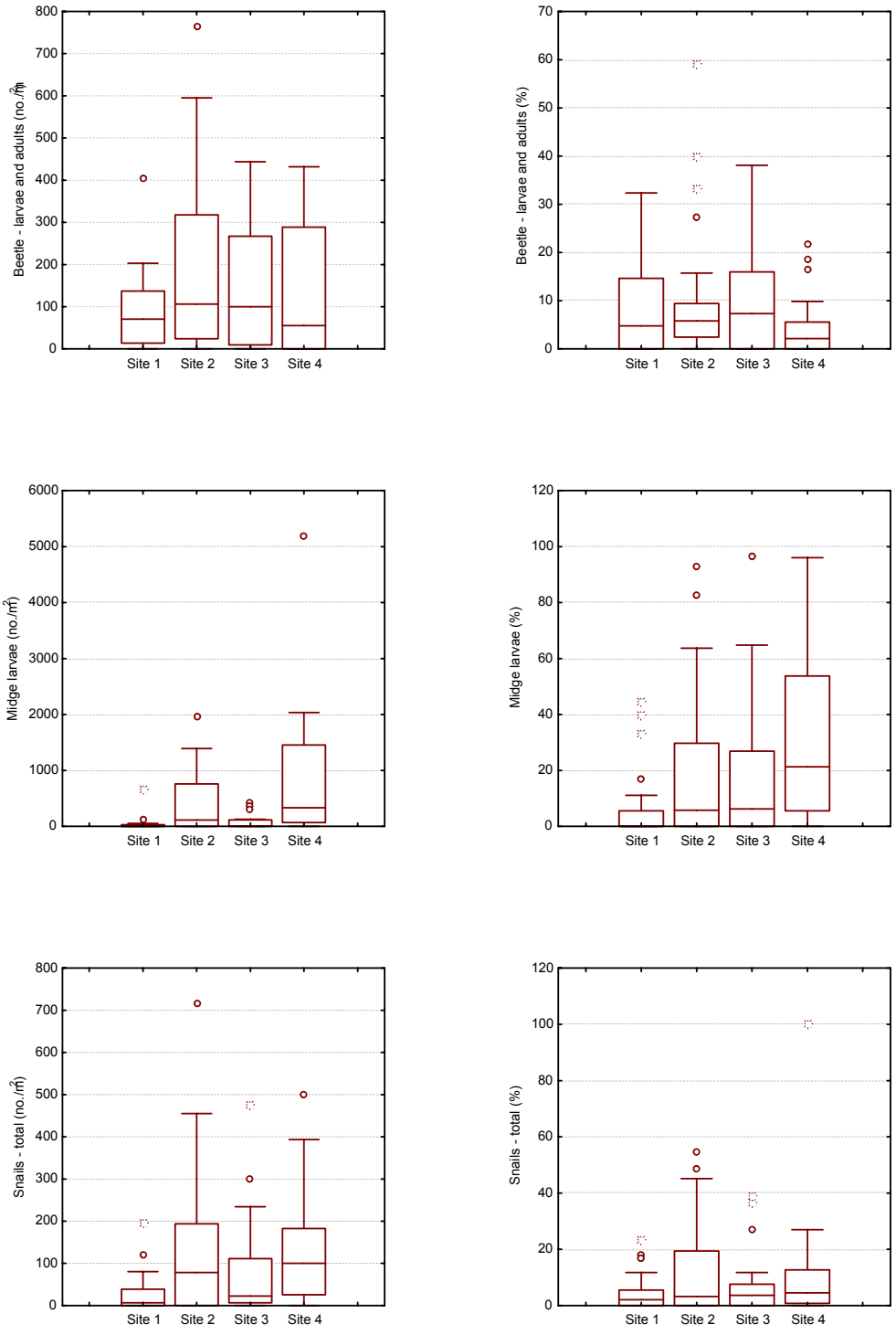

Figure 7.3 **Density and relative abundance (%) of the invertebrate groups found at the four sites on the Waipara River.**

Spearman rank correlation of the density and relative abundance data for the main invertebrate groups with periphyton biomass measurements are shown in Tables 7.2 and 7.3. Significant (p<0.05) positive correlations were found for the density of most invertebrate groups with chl. *a* and AFDM measurements. The relative abundance of worms, flatworms, midges, snails and ostracods positively correlated with chl. *a* and AFDM. However, the relative abundance of the caddisfly group, total caddisflies and EPT[6] negatively correlated with chl. *a* and AFDM.

The percent cover of medium thick mats and filaments correlated positively with worms, flatworms, snails, ostracods, midges and axehead caddisflies. In contrast, the density of snails, flatworms and midges negatively correlated with percent cover of thin films. While the density of total caddisflies and EPT positively correlated with long filaments and total cover of filaments, the relative abundance of these groups of invertebrates negatively correlated with medium thick and thick mats and filamentous algae and positively correlated with thin films of algae. The total density of invertebrates positively correlated with all biomass and percent cover measurements except for thin films. A significant negative correlation was found for thin films of periphyton and the density of invertebrates.

On a site by site comparison of overall invertebrate density with chl. *a* and AFDM values, sites 2, 3 and 4 positively correlated with invertebrate density (Table 7.4, Figure 7.4, Figure 7.5). There were no significant correlations of invertebrate density with biomass measurements as Site 1.

[6] EPT is the sum of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Tricoptera (caddisflies). These invertebrates are commonly grouped together as indicators of clean river waters and good river habitats. As no stoneflies were found in this study, the EPT values given are the sum of all caddisflies and mayflies.

Table 7.2 **Spearman rank correlation values of density data (combined data from all four sites) for the main invertebrate groups versus biomass and flow conditions. Shaded cells – *p<0.05.***

	Chl. a	AFDM	% Thin films	% Medium thick mats	% Thick mats	% Short filaments	% Long filaments	% Filaments	Accrual days	Surface velocity
Worms	0.365	0.315	-0.149	0.270	0.121	0.269	0.323	0.301	0.237	-0.025
Flatworms, leeches	0.543	0.595	-0.276	0.293	0.263	0.491	0.350	0.555	0.561	-0.469
Snails (*Potamopyrgus*)	0.529	0.507	-0.282	0.363	0.106	0.435	0.221	0.472	0.397	-0.365
Ostracods	0.447	0.453	-0.141	0.264	0.028	0.401	0.266	0.435	0.475	-0.451
Beetle larvae and adults	0.376	0.329	-0.048	0.033	-0.037	0.348	0.550	0.486	0.160	-0.423
Midges	0.433	0.393	-0.267	0.295	0.390	0.286	0.304	0.375	-0.112	0.038
Axehead caddis larvae	0.507	0.506	-0.171	0.286	0.261	0.371	0.254	0.390	0.531	-0.404
Caddisfly larve (several types)	-0.030	-0.054	0.008	-0.148	-0.196	-0.031	0.166	0.004	-0.075	-0.201
Caddisfly (*Olinga)*	-0.073	-0.007	-0.162	-0.142	0.064	-0.113	-0.017	-0.108	-0.051	0.094
Mayfly	0.099	0.047	-0.090	-0.072	-0.038	0.081	0.174	0.107	-0.085	-0.180
Snails - total	0.539	0.535	-0.283	0.372	0.156	0.448	0.201	0.473	0.432	-0.395
Caddisflies - total	0.248	0.211	-0.128	-0.007	0.023	0.159	0.260	0.218	0.158	-0.397
EPT (Caddisflies + mayflies)	0.248	0.204	-0.121	0.009	0.028	0.157	0.281	0.221	0.127	-0.408
Total density	0.665	0.592	-0.336	0.230	0.246	0.478	0.518	0.591	0.241	-0.471

Table 7.3 **Spearman rank correlation values of relative abundance (%) (combined data from all four sites) for the main invertebrate groups versus biomass and flow conditions. Shaded cells – *p<0.05.***

	Chl. A	AFDM	% Thin films	% Medium thick mats	% Thick mats	% Short filaments	% Long filaments	% Filaments	Accrual days	Surface velocity
Worms	0.38	0.29	-0.15	0.28	0.12	0.25	0.29	0.27	0.20	-0.03
Flatworms, leeches	0.47	0.56	-0.23	0.28	0.29	0.44	0.30	0.49	0.57	-0.45
Snails (*Potamopyrgus*)	0.22	0.22	-0.14	0.27	0.02	0.16	-0.02	0.15	0.17	-0.11
Ostracods	0.43	0.45	-0.14	0.22	0.01	0.39	0.28	0.43	0.49	-0.44
Beetle larvae and adults	0.09	0.11	0.17	0.06	-0.20	0.19	0.35	0.28	0.22	-0.34
Midges	0.27	0.21	-0.01	0.27	0.29	0.10	0.14	0.15	-0.11	0.21
Axehead caddis larvae	0.35	0.35	0.00	0.27	0.23	0.13	0.06	0.13	0.44	-0.29
Caddisfly larve (several types)	-0.44	-0.39	0.21	-0.30	-0.33	-0.23	-0.17	-0.25	-0.11	0.05
Caddisfly (*Olinga)*	-0.09	-0.04	0.01	-0.01	-0.02	-0.07	-0.04	-0.08	-0.09	0.10
Mayfly	-0.06	-0.10	0.03	-0.14	-0.13	0.00	0.09	0.03	0.05	-0.04
Snails - total	0.23	0.24	-0.14	0.28	0.06	0.17	-0.04	0.15	0.20	-0.13
Caddisflies - total	-0.40	-0.33	0.21	-0.25	-0.24	-0.28	-0.27	-0.32	-0.06	-0.01
EPT (Caddisflies + mayflies)	-0.40	-0.35	0.22	-0.26	-0.26	-0.27	-0.27	-0.32	-0.04	-0.02

Table 7.4 Spearman rank correlation invertebrate density with chlorophyll *a* and AFDM on a site by site basis.

		n	Spearman R	*p*
Site 1	Chl. *a*	22	0.16	0.468
	AFDM	22	0.04	0.861
Site 2	Chl. *a*	23	0.74	0.000
	AFDM	23	0.55	0.007
Site 3	Chl. *a*	20	0.73	0.000
	AFDM	20	0.72	0.000
Site 4	Chl. *a*	23	0.43	0.038
	AFDM	23	0.48	0.019

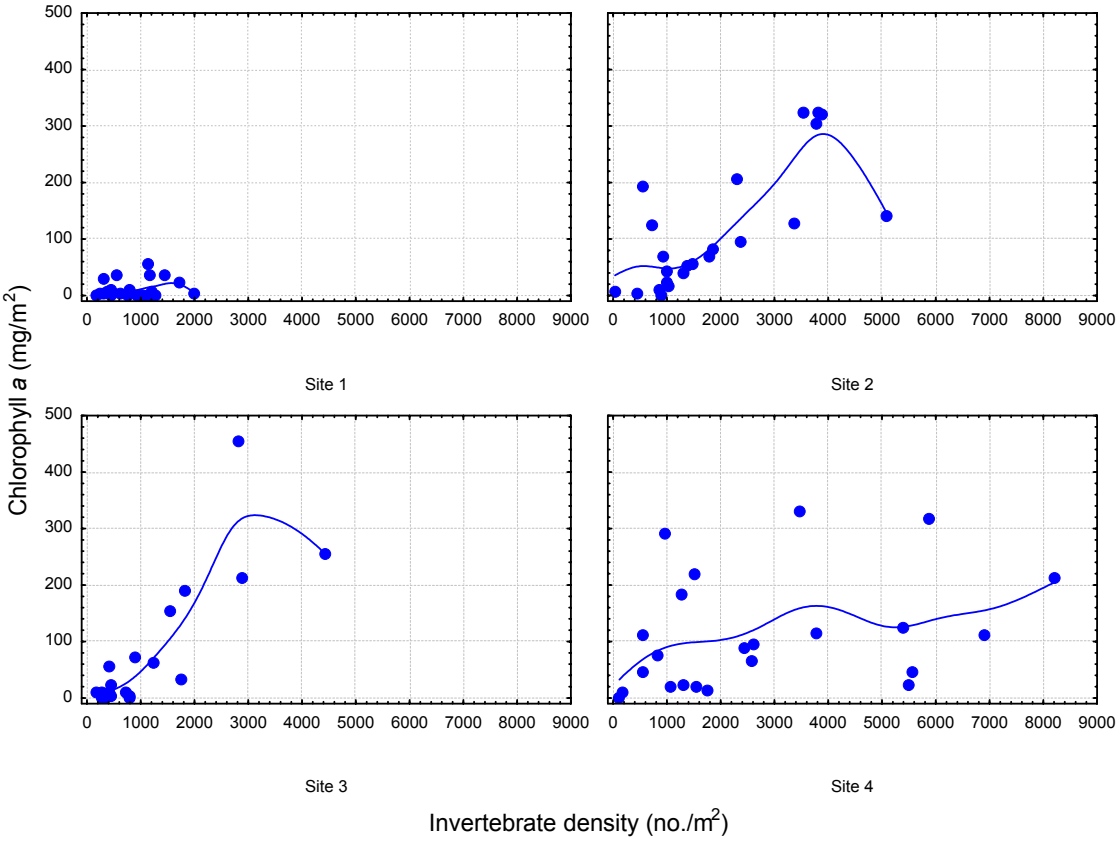

Figure 7.4 Scatterplot of chlorophyll *a* versus invertebrate density for each site.

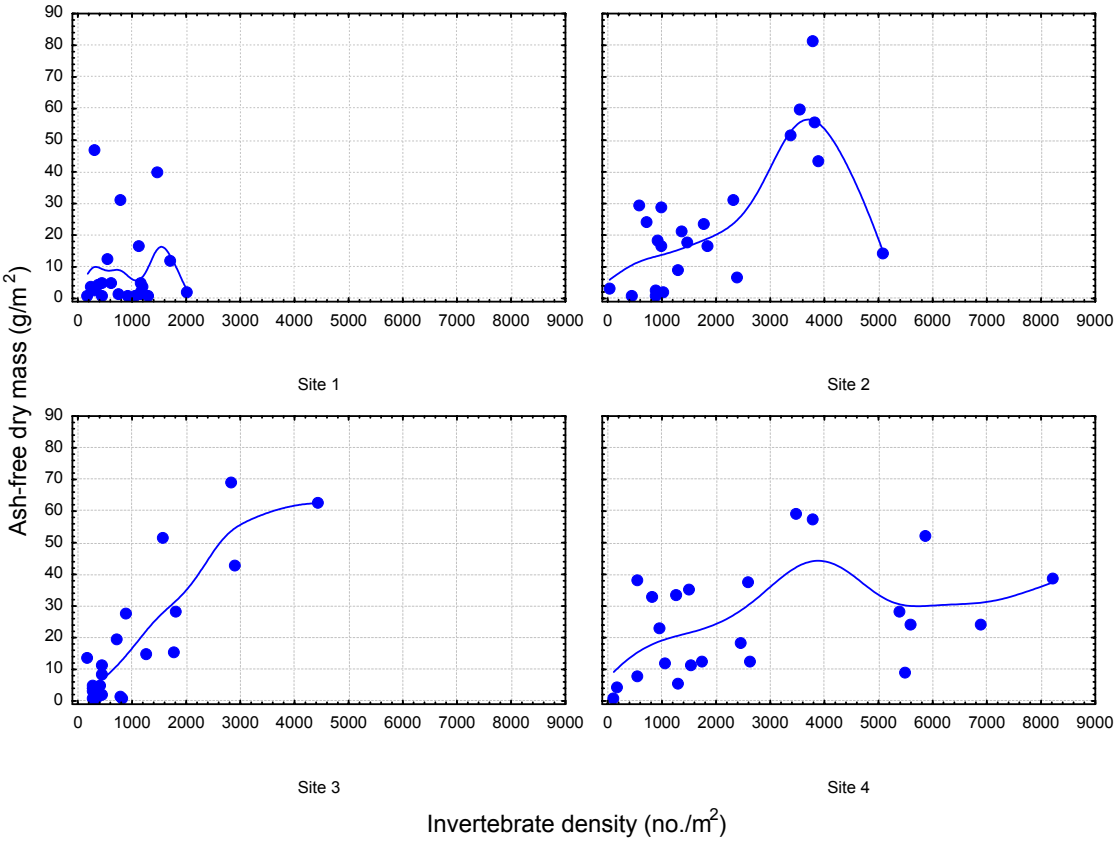

Figure 7.5 Scatter plot of ash-free dry mass versus invertebrate density for each site.

7.3 Discussion

The nature of data collected on invertebrates has allowed only a limited examination of their interaction with periphyton. Because each of the invertebrate groups often includes species with a variety of feeding habits, it was not possible to separate the density of grazing/browsing taxa from other invertebrates. Some of the groups were made up of primarily grazing/browsing species such as snails. However, in general each of the groups contained a mixture of grazers and other functional feeding groups. Therefore, general increases in invertebrate density is likely to indicate general increases in grazer densities.

The data showed an overall significant positive correlation of periphyton biomass (chl. *a* and AFDM) with total invertebrate density and with a number of invertebrate groups. On a site by site basis, the positive correlation of invertebrate density with chl. *a* and AFDM at site 2, 3 and

4 indicate that there is bottom-up control of periphyton. This is where growth is limited by resource availability (Rosemond *et al,,* 1993). Top-down control occurs where consumption by herbivores controls plant biomass. At sites 2, 3 and 4, invertebrate density appears to increase in response to increasing periphyton biomass. While many of the invertebrates present are able to graze on the periphyton, they do not appear to control its growth to a great extent. The high biomass that is able to develop at these sites suggest that periphyton growths rates are faster than the grazing ability of invertebrates.

At Site 1 there was not the same general pattern of increasing invertebrate density with increasing periphyton biomass. Densities of mayflies, caddisflies and beetles were highest at this site during the period of low stable flows. However, the periphyton biomass generally remained low, and increased only during the end of the low flow period (April to June). Invertebrate density generally decreased during this period, possibly due to reduced reproduction during winter months. It is likely that grazing invertebrates have a greater influence on periphyton biomass at this site than the other three sites. Grazers may be an important controller of biomass at this site, where periphyton accrual rates were low enough for invertebrates to exert grazing pressure. Similar results were found by Suren *et al.* (2003b) in a study comparing periphyton and invertebrates at a site on the lower reaches of the Waipara River compared to the nearby unenriched Okuku River. They found higher invertebrate densities at the Waipara River site associated with higher periphyton biomass. While the invertebrates densities were higher at this site than the Okuku River site, the relative abundance of grazing species was lower. Their results suggested that grazers have more of a controlling influence on periphyton biomass in unenriched rivers than in nutrient-enriched river systems.

The forms of algae present may also have an influence on whether invertebrates are able to effectively control biomass. Many grazing invertebrates have small mouth parts that are best suited to consuming small sized diatoms (Steimnan, 1996). At sites 2 and 4, the relatively rapid accrual of filamentous algae and large sized diatoms (e.g. *Synedra ulna* var. *biceps*) may limit the ability of grazers to control biomass. However, this does not appear to limit the density of grazers such as snails and the algal cell-piercing axehead caddisflies, which show general increase with increasing percent cover of filamentous algae and medium thick and thick mats.

While the periphyton growth at the lower three sites appears to stimulate invertebrate density, the relative abundance of some invertebrates groups are negatively affected by increasing biomass. The relative abundance of caddisflies and the EPT group generally decreased with increased periphyton biomass. These taxa are sensitive to water quality and stream habitat conditions, preferring unenriched, clean gravel streams. The loss of abundance of these sensitive taxa can have cascading effects on other stream biota. In particular, a number of native fish as well as introduced trout and salmon rely on many of these invertebrates as a major part of their diet.

Similar findings in term of low abundance of EPT taxa were found by Hayward *et al.* (2003). In their study, macro-invertebrate communities were sampled during summers from November 1999 to February 2003 at site 1 and 4 of this study. Overall invertebrate health grading for Site 1 was generally better than that of Site 4.

8 Conclusions

The Waipara River is in some ways an unusual river system within Canterbury. While being a small sized foothill-fed gravel river, one of many in Canterbury, its geographic and geological setting makes it less typical of other such rivers. Being located within a dry micro-climate as well as having poor water storage in the catchment, the river is prone to extreme flow regimes. Extended periods of low summer flows are a particular feature of this river, in which flows of less than 100 l/s (3% of mean flow) can last several weeks. Periods of low flows can extend well into winter months during some years. However, high volume floods can also occur. These are more frequent in winter and spring but can also occur at other times of year.

In a river classification system developed by NIWA, climatic, land use, and geological catchment features were used to classify rivers into ecologically significant groups (Snelder *et al*., 2000). All rivers in Canterbury have been classified. The Waipara River has quite unusual characteristics, being one of about four similarly sized rivers in Canterbury, which are hill-fed soft sedimentary rivers. The presence of 'soft sediments' (tertiary marine limestones and sandstones) in the catchment provides a natural source of inorganic nutrients (in particular phosphorus).

These combinations of broad-scale climatic and geological factors provide the potential for periphyton to develop to significant levels within the river system (Biggs & Close; 1989, Biggs, 1995). The data collected from this study has shown that indeed periphyton does develop to prolific levels in the lower reaches of the river as predicted by its broad-scale catchment features.

Periphyton biomass

In comparison to other New Zealand rivers, moderate to high periphyton biomass occurred at the three downstream sites, while a low biomass was generally found at the upstream site (Biggs, 1995, 2000, MfE, 2000). Recreational/aesthetic guidelines for periphyton were exceeded in most years at the site furthermost downstream, and were exceeded with moderate frequency at the two mid reach sites. Biomass at the uppermost site rarely exceeded these guidelines. This indicated that the aesthetic and recreational values of the river were somewhat degraded in its lower reaches.

Nutrient supply

Patterns in nutrient concentrations were complex. Average percent cellular N and P were highest at sites 2 and 4, and were indicative of nutrient enriched conditions. At sites 1 and 3, generally lower percent cellular nutrient values indicated mesotrophic conditions.

Dissolved nutrient concentrations were generally poor indicators of nutrient enrichment. In comparison to other hill-fed rivers in Canterbury, dissolved nutrient concentrations were generally low. Yet, most hill-fed rivers in Canterbury do not routinely develop periphyton biomass as high as that frequently found in the Waipara River (Environment Canterbury staff observations). In rivers such as the Waipara River, with moderate to high periphyton biomass, plant uptake of dissolved nutrients results in depleted concentrations in the water column.

Water conductivity proved a useful surrogate indicator of nutrient supply regimes. Annual and monthly conductivity values correlated positively with AFDM and chl. *a*, indicating the potential usefulness of conductivity for prediction of short term (monthly) and longer term (annual) biomass production. One hypothesis proposed in this study was that biomass would increase with distance downstream as a function nutrient enrichment. This was certainly the case where the uppermost site developed considerably less biomass than the downstream sites. However, spatial patterns in both nutrient concentrations and periphyton biomass tended to reflect local-scale habitat conditions rather than broad-scale catchment features as predicted, for example, by the River Continuum Concept (RCC) (Vannote *et al.* 1980).

Influence of flow regimes

Differences in flow regimes between two contrasting years resulted in notable differences in annual biomass production at three of the four sites. Maximum biomass values were considerably higher at these sites during the period of low stable flows than during an accrual period with greater frequency of spates and higher base flows. This supports the hypothesis proposed that low summer flows result in high algal biomass. However, despite the period of extended low flow, a high biomass did not develop at the nutrient-poor uppermost site.

The development of periphyton communities during the period of low stable flows appeared to be influenced by local hydraulic conditions. The highest percent cover of long filamentous growths occurred at sites 2 and 3 during the period of lowest water velocities. At Site 4, long

filamentous green algae did not develop to the same extent as at sites 2 and 3, instead thick mats and short filamentous growths dominated during low flows. The water velocities at this site were generally higher than at the upstream sites, which indicates that this is an important factor in determining the form of periphyton development.

Interaction of periphyton and invertebrates

The influence of invertebrate grazing on periphyton biomass also appears to be a function of the nutrient status of the river reach. At the three downstream sites, there was a strong positive correlation between invertebrate density and biomass production. These results suggest invertebrate density increases in response to increasing periphyton biomass. While grazing invertebrates undoubtedly resulted in some biomass loss, the rate of periphyton accrual appears to far exceed this loss from grazing.

At the uppermost, unenriched site, both periphyton biomass and invertebrate density were low compared to the downstream sites. There was no significant correlation between invertebrate densities and biomass measurements. This could be explained by the rate of periphyton biomass accrual being low enough that grazing invertebrates were limiting the extent of biomass production. This explains the relatively lower biomass at this site indicative of oligotrophic conditions compared to the nutrient status which indicated mesotrophic conditions.

Hierarchy of controlling factors

In a conceptual habitat matrix defined by gradients in disturbance frequency and resource supply (nutrients), the Waipara River can be defined as having a low disturbance frequency (<10 floods per year) and moderate to high resource supply (Biggs *et al.,* 1998b). Within this habitat matrix, the nutrient supply regime appears to be the primary control on periphyton development in the Waipara River. The effects of flow operate as the secondary control of biomass. This is indicated by different responses at each site to variations in flow regimes as a function of the nutrient status of each site.

Spatial patterns in biomass tended to reflect local habitat conditions rather than broad-scale catchment features. Biggs *et al.(*1998a) found periphyton community composition and biomass was more accurately predicted from local habitat factors than that predicted by

downstream changes in hydraulic conditions and enrichment. Similarly, in this study of the Waipara River, local habitat features, such as nutrient status, substrate stability and water velocities appeared to be major factors in determining biomass development at each site.

Management implications

Management of flow regimes in the river have the potential to influence the degree of degradation of the river by reducing periphyton proliferations. In particular, the development of nuisance growths of filamentous algae was related to periods of low stable flows where water velocities were low enough to allow long filamentous growth develop. Maintaining reasonable river flows may limit the development of these growths. However, during some years the natural flow regime of the river is such that flow management will have little impact.

Managing nutrient inputs from human activities may also help limit the extent of algal proliferations during low flows. At times of high biomass, both N and P may be limiting. Therefore, the addition of either of these nutrients may have a stimulatory effect on growth. While land use in the upper catchment consists of low intensity grazing and some forestry, the presence of grazing stock in the river bed during low flows have the potential to increase the N content of the river.

In the lower catchment, land uses are more intensive than the upper catchment. There is potential for nutrient from the surrounding land to enter the river, either via groundwater inflow or via more direct means. The general increase in N concentrations in water and periphyton from Site 3 to Site 4 suggests land use activities are impacting on the nutrient status of the lower reaches of the river. Limiting these inputs, especially of nitrogen, may help reduce periphyton biomass production.

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Appendix 1
Site Descriptions

Site	**Grid Reference for site location NZMS260 map series**	**Environment Canterbury Site I.D.**	**Run**	*1. Description*
Site 1 Laidmores Road	M34:7659-9410	CRC303962	Run 1: Jul 99 to Jan 2002	Approximately 300 m downstream of road entrance to riverbed.
Site 2 Stringers Bridge	M34:8293-9384	CRC302890	Run 1: Jul 99 to Aug 2000 Run 2: Sept 2000 to Jan 2002	Approximately 300 m downstream of bridge. Approximately 500 m downstream of bridge.
Site 3 Mt Cass Road	N34:9211-9224	CRC303476	Run 1: Jul 99 to Aug 2000 Run 2: Sept 2000 to Nov 2001	1 km upstream of road entrance to river, off Mt Cass Road. Near track entrance to river, approx. 700 m downstream of run 1.
Site 4 Teviotdale Bridge	N34:9202-8659	CRC300162	Run 1: Jul 99 to Aug 2000 Run 2: Sept 2000 to Jan 2002	Approximately 700 m upstream of bridge Immediately downstream of bridge

Appendix 2
Site habitat summary

Summary of substrate particle size assessments for each site

Run	Date	Number of particles in each size class					Median particle breadth (cm)
		Boulders >25 cm	Large cobbles 12 - 25 cm	Small cobbles 6 - 12 cm	Gravels 0.2 - 6 cm	Sand <0.2 cm	
Site 1							
1	Feb-00	0	0	5	87	8	3.2
1	Feb-01	0	0	8	89	3	2.8
Site 2							
1	Dec-99	0	4	12	80	4	3.1
2	Feb-01	0	0	9	89	2	3.0
Site 2							
1	Dec-99	0	4	15	78	3	2.4
2	Feb-01	0	0	0	99	1	2.4
Site 4							
1	Dec-99	0	2	21	76	1	3.0
2	Feb-01	0	0	6	94	0	2.3

Summary of size, depth and surface velocity of the monitoring sites

	Channel width (m)		Channel depth (cm)		Surface velocity (m/s).	
	mean	range	mean	range	mean	range
Site 1						
Run 1	11.8	4 - 18	26.8	13 - 41	0.5	0 - 1.2
Site 2						
Run 1	10.2	6 - 14	33.3	17 - 48	0.9	0.2 - 1.9
Run 2	9.6	6 - 17	34.0	22 - 52	0.5	0 - 1.6
Site 3						
Run 1	15.3	6 - 21	36.5	19 - 54	0.6	0.2 - 1.1
Run 2	9.2	7 - 15	28.4	13 - 54	0.7	0.3 - 1.5
Site 4						
Run 1	16.8	11 - 20	34.1	18 - 48	0.8	0.1 - 1.4
Run 2	12.7	6 - 22	32.9	19 - 58	0.8	0.4 - 1.4

Appendix 4
Stream health monitoring assessment forms

STREAM MONITORING FORMS

Date of survey: .....

Your name: .....

Farm name/address:.....

Stream/site name: .....

Weather conditions: .....

Did you take a photograph from the photo reference point? YES / NO

A. Recent flow conditions

Which category most closely describes the flow in this stream over the past six weeks?

	Stable flow	Brief flooding (for less than 2 days)	Several brief floods	Prolonged flooding (more than 5 days)	Prolonged low flows (no rain and unusually low water level)	enter category:
Category	**5**	**4**	**3**	**2**	**1**	

If your answer to this question is anything other than "Stable flow" then it would be preferable to postpone this monitoring until there has been a lead-in period of 4 to 6 weeks to allow stream conditions to stabilise. If you continue with your survey now, remember that the effects of flow conditions may be the most important influence on the apparent health of the stream. (***Note:*** the four-to-six-week period of stable flows may be quite impractical for some regions or for certain times of the year. You may *have* to monitor in high-flow conditions. However, your monitoring results may indicate that the stream is healthier than it would have been following a period of stable flow. In low flow conditions, the result may be a less healthy stream. **The important thing is to take account of flow conditions when you interpret the results.** For more information refer to **Unit 4. Planning a stream monitoring programme** and **Unit 9. Explanations of categories and scores**.)

Optional: take stream width and depth measurements as described in **Unit 5. How to get started** (section 5.4, pages **5.3-5.4**).

	Stream width	Stream depth			Average depth
		True left*	Centre	True right*	
at downstream site marker	_____ m	_____	_____	_____	_____
at centre of site	_____ m	_____	_____	_____	_____
at upstream site marker	_____ m	_____	_____	_____	_____

Note that the "True left" and "True right" banks are the left and right banks when you are looking downstream.

B. Recent farm conditions and activities

Answer these questions each time you monitor. The answers will assist in explaining the results. For example, if you have a single result that is much lower than the others you may be able to link this to some short term activity (e.g., weed clearance) that has disturbed the stream. Because you may not be aware of everything that has happened, especially if your stream comes through other properties, these results may not be complete. When you answer the questions, take into account the catchment for up to 1 km upstream, if possible, and consider events over the last 6 weeks.

Tick the boxes to record whether or not any of the following have occurred, to your knowledge, over the last 6 weeks. Include authorised activities (i.e., with a consent) and unauthorised or accidental pollution (i.e., spills, spray drift, etc.).

Inputs into and disturbances in stream	**Yes**	**No**	**Maybe**
Stock wandering in channel			
Routine stock crossings in the stream			
Pollutants: Untreated animal / human wastes			
Treated animal / human wastes			
Fertiliser			
Agrichemicals (pesticides, herbicides, etc.)			
Petroleum products			
Factory waste			
Effluent from silage			
Stormwater (e.g., from buildings or yards)			
Field drains			
Water abstractions from stream			
Other (specify ……)			

Activities within 500 m of the stream			
Weed or silt clearance in or around the stream			
Earthworks (e.g., track building or maintenance)			
Tree harvesting			
Bank vegetation removal			
Other (specify ……)			

For further discussion on the effects of different activities on stream health refer to **Unit 10. Farm practices and stream health.**

C. Habitat quality

Flow velocity

Measure the speed of the water flow by timing an object floating down the length of the site (or a part of the length) in the centre of the stream. Take the average of three measurements.

Distance travelled:		Time:	1	2	3	Average time:	

Average water velocity = Distance travelled/average time = _____ metres/sec

	Under 0.1 m/s	0.1 to 0.29	0.3 to 0.69	0.7 to 0.99	1.0 or more	enter score:
score:	**1**	**8**	**10**	**5**	**3**	

Water pH

Use pH indicator strips to measure the pH of a sample of stream water from the main flow.

Measured pH: _____

	5 or less	5.5 to 6	6.5 to 7.5	8 to 9	9.5 or more	enter score:
score:	**-5**	**5**	**10**	**5**	**-5**	

Water temperature

Measure water temperature in the main flow, in an undisturbed area.

Measured temperature: _____ °C Time of day: _____

	Under 5 °C	5 to 9.9	10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 or more	enter score:
score:	**5**	**8**	**10**	**8**	**5**	**1**	**-5**	

Water conductivity

Measure the conductivity of a water sample, from the main flow, using the meter provided.

Measured conductivity: _____ μSiemens/cm

	Under 50	50 to 149	150 to 249	250 to 399	400 or more	enter score:
score:	**20**	**16**	**10**	**6**	**1**	

Water clarity

Measure the clarity of a water sample using the clarity tube (average of three readings).

Measured clarity:	1	2	3	cm (from viewing end to disc surface)	Average cm:	

	Clear to bottom (=100)	70 to 99	55 to 69	35 to 54	under 35 cm	enter score:
score:	**10**	**8**	**5**	**3**	**1**	

C. Habitat quality *(continued)*

Composition of the stream bed

Estimate by eye the percentages (to the nearest 10%) of cover of different types of material making up the stream bottom (see scale on ruler). (See page 6.15 for a more precise method.)

	Bed-rock	Boul-ders (> 25cm)	Large cobbles (12-25cm)	Small cobbles (6-12cm)	Gravels (0.2-6 cm)	Sand	Mud or silt	Man-made (eg, con-crete)	Woody debris	Water plants (rooted in the stream bed)	
score:	**-10**	**10**	**20**	**10**	**0**	**-10**	**-20**	**-20**	**0**	**0**	Total:
enter % :											100
score x %											

enter total of (score x %) | overall score = total (score x %) / 100 (maximum score = 20) | enter score:

Deposits

Note whether any loose deposited material is on the stream bed.

	None noticed	Fine (less than 1 mm thick), mainly in edge areas	Moderate (up to 3 mm), edge areas and elsewhere	Moderate to thick (3 mm or more) patchy , most of bed	Thick (over about 5 mm) on most horizon-tal surfaces	enter score:
score:	**10**	**5**	**0**	**-5**	**-10**	

Bank vegetation

For each bank along the 10 metre length of the site estimate the percentage (to the nearest 10%) covered by the listed vegetation types in a strip 5 metres wide parallel to the water's edge.
Note: the true left and true right are the left and right sides looking downstream.

	Native trees	Wet-land vegeta-tion	Tall tussock grass-land, not improved	Intro-duced trees (willow, poplar...)	Other intro-duced trees (conifers)	Scrub	Rock, gravels	Short tussock grass-land, improved	Pasture grasses and weeds	Bare ground, roads, build-ings	
score:	**10**	**10**	**8**	**8**	**5**	**5**	**5**	**3**	**-10**	**-10**	Total:
%, true left:											100
%, true right											100
total % (L + R)											200
total % x score											

enter total of all (score x %) | overall score = total (score x %) / 100 (i.e., average L and R bank scores added) (maximum possible score = 20) | enter score:

Now add the scores for all questions and transfer to the *Monitoring record*.

Also note any scores which are at the very low end of their range.

Total score:

N.B. Complete ***either*** D1 ***or*** D2

D2 Stream-bed life: Level 2

For each of 10 stones, sediment or water plant samples, record the number of "indicator" invertebrates for each category and then the estimated % coverage of the exposed part of the stone by each type of periphyton. (See over for calculating biological scores for this site.)

Invertebrates		**Sample number:**									
	Invert score	**Transect 1** (if applicable)					**Transect 2** (if applicable)				
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Enter type of sample (stone, gravel, silt, plant, etc.):											
Worms (e.g. thin brown/red)	**1**										
Flatworms, leeches	**3**										
Freshwater crustaceans (amphipods, water fleas)	**5**										
Small bivalves (up to 4 mm across)	**3**										
Snails (4–6 mm across, rounded)	**3**										
Snails (1–3 mm across, pointed end)	**4**										
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**										
"Axehead" caddis (*Oxyethira*, 2–3 mm long)	**3**										
Midge larvae (3–7 mm long, white - red)	**2**										
Damselfly larvae	**4**										
Cranefly larvae	**5**										
Beetle larvae and adults	**6**										
Caddisfly larvae (rough stony cases, or cases of	**6**										
Smooth-cased caddisfly larvae (*Olinga*, up to 10	**9**										
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**										
Mayfly larvae (2–15 mm long)	**9**										
Stonefly larvae (large species, up to 20 mm)	**10**										

Periphyton (on exposed surfaces)			**Stone number:**									
		Peri. score	**Transect 1** (if applicable)					**Transect 2** (if applicable)				
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Thin mat/film:	green	**7**										
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/ light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**										
(over 2 cm long)	brown/reddish	**4**										

Appendix 5
Summary of relative abundance scores of algae

Summary of periphyton relative abundance scores

Number	*Taxa*	Site 4			Site 3			Site 2			Site 1		
		Ave	Max	*Count*	Ave	Max	*Count*	Ave	Max	*Count*	Ave	Max	*Count*
Blue-greens													
69	*Oscillatoria sp.1*	**1**	1	*1*				**0**	0	*1*	**1**	1	*1*
70	*Phormidium sp.1*	**2**	7	*21*	**1**	5	*14*	**2**	5	*19*	**1**	4	*20*
72	*Tolypothrix sp.1*	**1**	1	*1*	**0**	0	*1*	**0**	0	*1*	**1**	3	*5*
73	*Anabaena sp.1*	**2**	2	*1*	**1**	1	*2*	**1**	2	*3*	**2**	4	*9*
74	*Lynbya/Heteroleibleinia sp.*	**1**	2	*9*	**1**	1	*11*	**1**	3	*12*	**2**	6	*14*
117	*Dichothrix*	**1**	1	*2*	**2**	6	*4*	**0**	0	*1*	**2**	6	*10*
118	Unknown P*homidium* type	**1**	1	*1*									
122	*Rivularia*				**1**	1	*4*	**1**	1	*1*	**2**	4	*4*
Chlorophyta - colonial													
108	*Ankistrodesmus*	**1**	1	*2*	**1**	1	*4*	**1**	2	*8*	**1**	2	*6*
109	Unicel unknown							**2**	2	*1*			
20	*Scenedesmus sp.1*	**1**	3	*14*	**1**	2	*11*	**1**	2	*9*	**1**	2	*8*
21	*Scenedesmus sp.2*	**2**	3	*14*	**2**	3	*12*	**1**	3	*10*	**1**	3	*12*
22	*Scenedesmus sp.3*	**0**	0	*1*	**0**	1	*6*	**2**	3	*3*	**0**	0	*1*
23	*Scenedesmus sp.4*	**2**	3	*7*	**1**	1	*4*	**1**	1	*1*	**0**	1	*5*
25	*Scenedesmus sp.6*	**0**	1	*9*	**1**	2	*10*	**1**	1	*8*	**1**	3	*4*
26	*Tetrasporales sp.1*										**0**	0	*1*
27	*Pediastrum sp.1*	**1**	1	*5*	**1**	2	*8*	**1**	2	*4*	**0**	1	*5*
29	*Scenedesmus sp.7*	**1**	3	*10*	**1**	3	*12*	**1**	3	*9*	**1**	3	*11*
76	*Scenedesmus sp. 8*	**1**	3	*10*	**1**	2	*7*	**1**	2	*8*	**1**	1	*8*
121	*Pediastrum sp2*	**0**	0	*2*	**0**	1	*4*	**1**	1	*1*			
135	*Pediastrum sp3*	**0**	0	*1*									
18	*Cosmarium sp.1*	**1**	4	*13*	**1**	3	*10*	**2**	4	*10*	**1**	2	*10*
19	*Closterium sp.2*							**0**	0	*2*			
28	*Tetraedron sp.1*				**0**	0	*1*						
Chlorophyta - filamentous													
1	*Ulothrix zonata*	**2**	7	*20*	**2**	4	*13*	**2**	5	*20*	**2**	7	*15*
2	*Ulothrix aequalis*	**1**	2	*3*	**1**	1	*3*	**1**	2	*6*	**1**	1	*1*
3	*Ulothrix tenuissima*							**1**	1	*1*	**2**	2	*1*
4	*Geminella minor*	**0**	0	*1*							**1**	1	*1*
5	*Cladophora glomerata*	**4**	8	*20*	**4**	7	*11*	**5**	8	*18*	**2**	3	*2*
6	*Cladophora sp1*				**1**	1	*1*				**1**	1	*1*
7	*Stigeoclonium lubricum*	**3**	7	*17*	**2**	5	*13*	**3**	7	*12*	**2**	4	*15*
8	*Oedogonium sp.1*	**3**	6	*8*	**3**	7	*9*	**1**	2	*8*	**1**	2	*7*
9	*Oedogonium sp.2*	**2**	4	*12*	**3**	5	*10*	**1**	3	*12*	**1**	2	*6*
10	*Oedogonium sp.3*	**1**	2	*5*	**2**	6	*6*	**2**	3	*8*	**3**	8	*3*
11	*Mougeotia sp.1*										**1**	1	*1*
12	*Mougeotia sp.2*	**1**	1	*1*	**0**	0	*2*				**1**	1	*3*
13	*Zygnema sp.1*				**4**	8	*6*	**2**	2	*2*	**0**	0	*2*
14	*Spyrogyra sp.1*	**1**	1	*2*	**1**	2	*8*	**1**	1	*5*	**3**	6	*4*
15	*Spyrogyra sp.2*							**6**	6	*1*			
16	*Spyrogyra sp.3*										**0**	0	*1*
79	*Unknown filament*	**1**	1	*2*	**1**	2	*4*	**1**	2	*7*	**1**	3	*9*
80	*Klebsormidium sp.1*				**0**	0	*2*						
88	*Chaetophora*	**3**	3	*1*									
89	*Mougeotia sp.3*	**1**	3	*8*	**2**	6	*11*	**1**	3	*11*	**3**	7	*11*
129	*Odeogonium sp. 4*	**1**	1	*2*	**1**	1	*1*	**2**	2	*2*	**1**	1	*1*

Summary of periphyton relative abundance scores (continued)

Number	*Taxa*	Site 4			Site 3			Site 2			Site 1		
		Ave	Max	*Count*	Ave	Max	*Count*	Ave	Max	*Count*	Ave	Max	*Count*
Diatoms													
30	*Melosira varians*	**4**	8	*25*	**3**	8	*17*	**4**	8	*22*	**4**	8	*22*
31	*Cocconeis pediculus*	**5**	8	*21*	**5**	8	*20*	**5**	8	*23*	**2**	4	*18*
32	*Cocconeis placentula*	**3**	4	*22*	**3**	4	*20*	**3**	4	*24*	**4**	8	*23*
33	*Navicula lanceolata*	**4**	8	*18*	**3**	8	*15*	**3**	8	*19*	**2**	8	*20*
34	*Gomphoneis*	**1**	3	*8*	**2**	6	*7*	**1**	2	*10*	**2**	4	*8*
35	*Naviculoid sp.2*	**3**	8	*25*	**3**	8	*21*	**3**	8	*24*	**3**	7	*22*
36	*Navicula capitoradiatu*	**2**	6	*24*	**3**	5	*19*	**3**	5	*23*	**3**	5	*23*
37	*Synedra acus*	**2**	5	*19*	**2**	4	*17*	**3**	7	*19*	**3**	5	*16*
38	*Nitzschia c.f. acicularis*	**1**	1	*6*	**1**	1	*6*	**1**	2	*6*	**1**	2	*6*
39	*Synedra ulna var.1*	**3**	8	*20*	**3**	6	*14*	**2**	8	*20*	**3**	8	*17*
40	*Synedra delicatissima*	**0**	0	*1*	**1**	1	*1*	**1**	1	*1*	**0**	0	*1*
41	*Synedra ulna var biceps*	**4**	8	*22*	**5**	8	*14*	**5**	8	*16*	**2**	5	*13*
42	*Cymbella tumida*	**1**	4	*18*	**2**	6	*17*	**2**	5	*20*	**3**	7	*19*
43	*Encyonema minutum*	**3**	8	*23*	**2**	5	*18*	**2**	4	*22*	**3**	7	*15*
44	*Encyonema caespitosum*	**2**	3	*16*	**1**	1	*8*	**1**	2	*10*	**1**	3	*5*
45	*Gomphoneis minuta var cassieae*	**5**	8	*25*	**4**	8	*20*	**5**	8	*24*	**5**	8	*21*
46	*Gomphonema c.f. minutum*	**2**	4	*23*	**4**	8	*19*	**3**	7	*24*	**4**	8	*20*
47	*Achnanthidium linearis*	**2**	4	*19*	**2**	3	*16*	**2**	3	*20*	**1**	2	*10*
48	*Diatoma tenuis*	**2**	4	*10*	**1**	3	*3*	**2**	4	*6*	**1**	2	*5*
49	*Diatoma sp.2*	**2**	3	*10*	**2**	3	*5*	**2**	6	*9*	**2**	3	*3*
50	*Epithemia sorex*	**3**	5	*17*	**4**	8	*20*	**4**	8	*18*	**5**	8	*22*
52	*Unknown sp*	**2**	4	*10*	**1**	3	*7*	**2**	4	*8*	**1**	5	*8*
53	*Surirella minuta*	**1**	3	*11*	**1**	2	*4*	**1**	2	*5*	**1**	1	*4*
54	*Planothidium lanceolatum*	**2**	6	*13*	**1**	3	*9*	**1**	2	*6*	**2**	4	*10*
55	*Cymbella aspera*										**0**	0	*1*
57	*Gomphonema acuminatum*	**0**	0	*3*	**0**	0	*1*	**1**	2	*6*	**0**	0	*3*
58	*Fusigilaria sp.2*	**1**	1	*2*				**1**	1	*1*			
59	*Fragilariforma sp.1*	**1**	1	*2*	**1**	1	*1*	**1**	1	*4*	**1**	1	*1*
60	*Navicula cuspidata var ambigua*										**1**	1	*8*
61	*Navicula cryptocephata*	**1**	1	*2*	**1**	1	*2*	**1**	2	*6*	**1**	1	*8*
62	*Gomphonema clavatum*	**0**	0	*1*	**1**	2	*6*	**1**	2	*7*	**1**	1	*4*
63	*Achnanthidium minutissimum*	**2**	4	*18*	**2**	3	*15*	**1**	3	*16*	**1**	1	*4*
64	*Gomphonema truncatum*	**1**	3	*10*	**2**	4	*7*	**2**	5	*12*	**1**	2	*11*
66	*Nitzschia c.f. palea*	**4**	6	*25*	**3**	5	*20*	**3**	5	*23*	**4**	8	*20*
67	*Cymbella kappii*	**4**	8	*24*	**5**	8	*21*	**4**	8	*24*	**5**	8	*23*
90	*Synedra ulna var ramesi*	**4**	8	*16*	**3**	8	*12*	**4**	7	*14*	**3**	7	*11*
91	*Fragilaria vaucheria*	**2**	4	*20*	**2**	5	*12*	**2**	5	*19*	**2**	3	*12*
92	*Fragilaria capucina*	**4**	8	*12*	**3**	8	*12*	**3**	6	*14*	**2**	4	*10*
93	*Naviculoid*							**0**	0	*1*			
94	*Nitzschia c.f. linearis*	**1**	4	*11*	**2**	3	*8*	**1**	4	*10*	**1**	3	*10*
95	*Naviculoid*	**1**	2	*13*	**3**	4	*11*	**2**	5	*14*	**2**	3	*3*
96	*Rhoicosphenia abbreviata*	**1**	1	*7*	**0**	1	*8*	**0**	1	*12*	**1**	2	*17*
97	*Nitzschia sigmoidiae*	**0**	1	*7*	**0**	1	*5*	**1**	1	*14*	**1**	2	*8*
98	*Reimeria sinuata*	**2**	3	*19*	**1**	3	*13*	**1**	2	*23*	**1**	2	*16*
100	*Rhopalodia novae-zealandiae*	**0**	0	*1*	**1**	1	*3*	**1**	1	*6*	**3**	6	*12*
101	*Naviculoid*	**1**	2	*8*	**0**	1	*3*	**1**	1	*11*	**1**	1	*4*
102	*Nitzschia gracilis*	**1**	1	*3*	**0**	1	*3*	**1**	1	*3*	**1**	3	*4*
103	*Epithemia adnata*				**0**	0	*1*	**1**	2	*5*	**0**	1	*7*
104	*Synedra ulna var contracta*	**2**	7	*19*	**3**	8	*12*	**3**	8	*17*	**2**	6	*17*
105	*Synedra rumpens*	**1**	1	*1*	**5**	7	*2*	**1**	1	*1*			
106	*Frustulia c.f. vulgaris*	**0**	0	*1*							**0**	0	*1*
110	*Navicula radiosa*	**1**	1	*2*	**1**	1	*4*	**1**	4	*9*	**1**	2	*13*
111	*Gomphonema parvulum*	**1**	3	*12*	**1**	2	*8*	**1**	2	*6*	**1**	3	*9*
112	*Nitzschia c.f. disspitata*	**1**	1	*2*	**0**	0	*2*	**0**	1	*3*	**1**	1	*2*
113	*Frustulia rhomboides*	**1**	1	*2*							**1**	1	*2*
114	*Filamentous diatom*	**2**	3	*4*	**1**	1	*3*	**1**	2	*6*	**2**	3	*10*
115	*Nitzschia sp*	**3**	6	*12*	**3**	6	*11*	**3**	7	*15*	**2**	5	*17*
116	*Gomphonema angustum*	**2**	3	*2*	**1**	1	*5*	**1**	1	*4*	**1**	1	*1*
125	*Gomphonema montanum*	**1**	1	*4*	**0**	0	*1*				**3**	3	*1*
130	*Naviculoid*							**7**	7	*1*			